



This is a digital copy of a book that was preserved for generations on library shelves before it was carefully scanned by Google as part of a project to make the world's books discoverable online.

It has survived long enough for the copyright to expire and the book to enter the public domain. A public domain book is one that was never subject to copyright or whose legal copyright term has expired. Whether a book is in the public domain may vary country to country. Public domain books are our gateways to the past, representing a wealth of history, culture and knowledge that's often difficult to discover.

Marks, notations and other marginalia present in the original volume will appear in this file - a reminder of this book's long journey from the publisher to a library and finally to you.

Usage guidelines

Google is proud to partner with libraries to digitize public domain materials and make them widely accessible. Public domain books belong to the public and we are merely their custodians. Nevertheless, this work is expensive, so in order to keep providing this resource, we have taken steps to prevent abuse by commercial parties, including placing technical restrictions on automated querying.

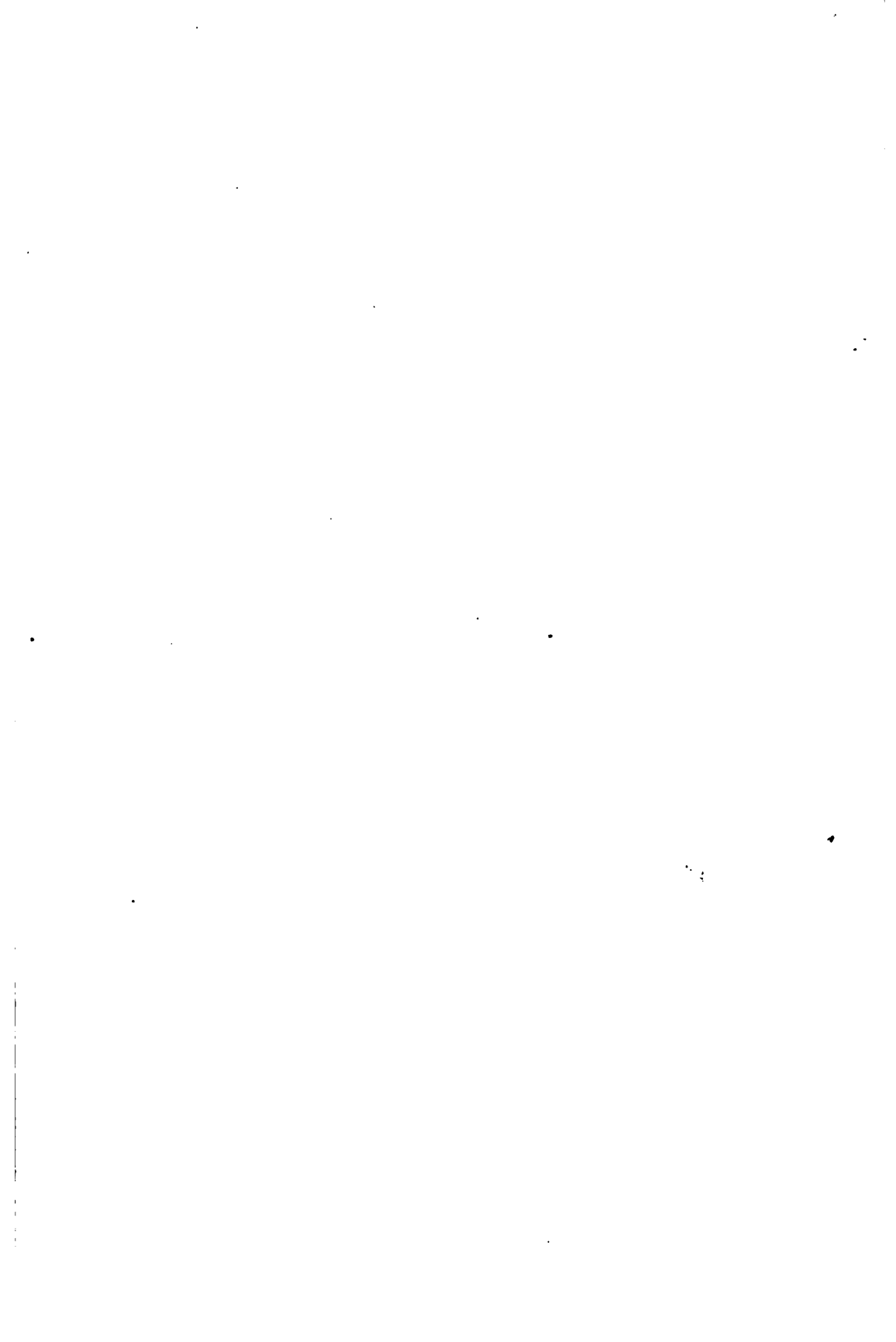
We also ask that you:

- + *Make non-commercial use of the files* We designed Google Book Search for use by individuals, and we request that you use these files for personal, non-commercial purposes.
- + *Refrain from automated querying* Do not send automated queries of any sort to Google's system: If you are conducting research on machine translation, optical character recognition or other areas where access to a large amount of text is helpful, please contact us. We encourage the use of public domain materials for these purposes and may be able to help.
- + *Maintain attribution* The Google "watermark" you see on each file is essential for informing people about this project and helping them find additional materials through Google Book Search. Please do not remove it.
- + *Keep it legal* Whatever your use, remember that you are responsible for ensuring that what you are doing is legal. Do not assume that just because we believe a book is in the public domain for users in the United States, that the work is also in the public domain for users in other countries. Whether a book is still in copyright varies from country to country, and we can't offer guidance on whether any specific use of any specific book is allowed. Please do not assume that a book's appearance in Google Book Search means it can be used in any manner anywhere in the world. Copyright infringement liability can be quite severe.

About Google Book Search

Google's mission is to organize the world's information and to make it universally accessible and useful. Google Book Search helps readers discover the world's books while helping authors and publishers reach new audiences. You can search through the full text of this book on the web at <http://books.google.com/>





**BLAST-FURNACE CONSTRUCTION
IN AMERICA**

McGraw-Hill Book Company

Publishers of Books for

Electrical World	The Engineering and Mining Journal
Engineering Record	Engineering News
Railway Age Gazette	American Machinist
Signal Engineer	American Engineer
Electric Railway Journal	Coal Age
Metallurgical and Chemical Engineering	Power

BLAST-FURNACE CONSTRUCTION IN AMERICA

BY

J. E. JOHNSON, JR.

FIRST EDITION

1917
Copyright

McGRAW-HILL BOOK COMPANY, INC.
239 WEST 39TH STREET, NEW YORK

LONDON: HILL PUBLISHING CO., LTD.

6 & 8 BOUVERIE ST., E.C.

1917

7.11

COPYRIGHT, 1917, BY
THE MCGRAW-HILL BOOK COMPANY, INC.

70 1111
1111111111

TO
JAMES GAYLEY
FOUNDER OF MODERN AMERICAN BLAST-FURNACE PRACTICE
INVENTOR OF THE DRY BLAST
GENEROUS AND HELPFUL FRIEND TO MANY FURNACEMEN
*THIS WORK
IS RESPECTFULLY DEDICATED*

370144

PREFACE

THE blast-furnace is the key which unlocks Nature's stores of iron for our use. It is unique in having been unchanged in principle for several centuries, and in having no substitute. For the steam engine we have the gas engine, for the Bessemer converter the open-hearth, but if the blast-furnace were taken from us, civilization would be halted.

It is the most complex in principle and the most difficult to operate successfully of any metallurgical apparatus, and its proper understanding probably requires more years of study than any other industrial operation; for all these reasons it deserves the profoundest investigation and consideration.

It is surprising that in nearly half a century, since the publication of Sir Lothian Bell's last work, no comprehensive book on this subject has appeared in any language, and a growing need has been felt for one.

I happen to have made several investigations which served to explain some of the phenomena of the blast-furnace not previously understood, and it seemed proper that the results should be recorded, for if they are right, they will save others the time and trouble of going over the same ground again, and if they are wrong, they will inspire the oncoming generation to prove them so, and in the end will, even by that circuitous route, lead to the truth at last. This is my reason and must be my apology, if any be needed, for attempting to treat a subject of such magnitude and difficulty. The best efforts of my leisure for more than three years have been spent upon the work, but the subject is too vast for one man to do it justice.

In many cases my own opinions are given for what they may be worth, because it seems to me that those books which simply give a number of opinions without any indication of the author's preference are of little real use. Nevertheless, I have tried to distinguish clearly between proven facts and my own opinions; for this reason I have used the first person throughout.

The book is deficient as regards the history of its subject, for the reason that I know little about the early history of the blast-furnace and have but little faculty for historical investigation. I have attempted to give enough recent history to show the present trends in the industry, and to make a presentation, not of an industry in a static condition, but of one undergoing a healthy evolution.

It will be noted that, as the title implies, the book contains little or nothing on foreign blast-furnaces; this is not because these are unworthy of attention, but because my very limited knowledge of that portion of the subject did not permit me to do it justice, and I was unwilling to give a second-hand treatment of it.

I wish to acknowledge the help I have received in the form of facts and ideas from nearly all the furnacemen I have met. I have tried to make specific acknowledgment in the text to those who have given me the most valuable information; undoubtedly I have missed some, but the omission was unintentional.

To Dr. E. F. Roeber, the Editor of "Metallurgical & Chemical Engineering," in which the book first appeared as a series of articles, I make here my profound acknowledgment of his helpfulness, patience, appreciation and encouragement.

To Mr. D. M. Liddell, author of the "Metallurgists' & Chemists' Hand Book," my sincere thanks are tendered for reading over my manuscript and finding in it many obscure paragraphs and errors whose presence I suspected, but, owing to too great familiarity with the text, could not see.

To Mr. Bradley Stoughton, Secretary of the American Institute of Mining Engineers, I am indebted for helpful and constructive criticisms on several of the chapters.

My attempt to cover the field has outrun the limits of one volume, and this will shortly be followed by a companion volume, "The Principles, Operation and Products of the Blast Furnace." The separation into two volumes is merely for convenience.

J. E. J. JR.

CONTENTS

PREFACE	vii
INTRODUCTION.	1
Fundamental Conditions. — Definition of the Blast-furnace. — Classification by fuels used. — Essentials of plant. — Additional requirements. — Characteristics required of the fuel. — Freedom from sulphur and phosphorus. — Porosity. — Physical strength. — The magnitude and components of the plant.	
CHAPTER I	
HANDLING THE RAW MATERIALS	7
Stock hoisting. — Hand-filling and filling-barrows. — The Duquesne revolution. — The delivery of the stock to the furnace. — Ore-handling machinery — Car dumpers — Power used. — Design of bins. — Methods of hoisting in mechanical charging. — Location of the hoisting sheaves. — Dumping the skip. — Counterweighting. — Larry cars. — Scales.	
CHAPTER II	
FILLING THE BLAST-FURNACE	48
The laws of stock distribution. — Variations of the bell and hopper used with hand-filling. — The gas seal. — Mechanical charging. — Skip filling. — The Roberts top. — The Rowe top. — Breakage of the coke. — Rotating tops. — The Brown top. — The Baker top. — The McKee top. — The bucket system of distribution. — The Neeland top — Ford-Parkes top. — Guiding the bell movement. — Bell-operating apparatus. — Provisions for access and repairs. — Handling the bells for repairs. — The stock line recorder.	
CHAPTER III	
THE BOILER PLANT	99
Horizontal tubular boilers. — General considerations concerning water-tube boilers. — The Heine boiler. — The Babcock & Wilcox boiler. — The Stirling boiler. — The Rust boiler. — Gas burners for boilers. — Boiler cleaning.	
CHAPTER IV	
BLOWING APPARATUS	119
Air valves. — Corliss valves. — Pot valves. — The Southwark air valve. — The return to automatic valves. — Methods of compounding. — Inertia of reciprocating parts. — The disconnected compound. — Review of different types of engines. — The vertical quarter-crank engine. — The horizontal-vertical. — The long cross-head type. — The steeple type or vertical tandem cross-compound. — The horizontal cross compound with tandem air cylinders. — The tail slide. — The inside-crank engine. — Steam valves and their settings. — The turbo	

blower. — The Southwark turbo blower. — The General Electric blower. — The disadvantages of the turbo blower. — Pulsation of discharge. — Inefficiency. — Failures. — The condenser. — Combination of turbine and reciprocating engine. — The gas-driver blowing engine. — The difficulties to be overcome. — The cleaning of the gas. — Adapting the engine to variable loads. — Adapting the engine to run double-acting with tandem cylinders. — Elimination of difficulties and uncertainties of operation. — Expenses of operation and maintenance. — The reduction of the gas engine to standard practice. — Type of gas engines. — The speeds of gas engines. — The choice of a type of blowing engine. — Outline of the solution.

CHAPTER V

HOT-BLAST STOVES 190

The iron-pipe stove. — The joints. — Baffle walls. — The roof of the stove. — The shape of the pipes. — Two types of iron-pipe stoves. — Firebrick stoves. — The three-pass central combustion chamber stove. — The McClure stove. — The Roberts three-pass stove. — Two-pass stoves. — Two-pass side combustion chamber stoves. — The Nelson two-pass stove. — Roberts two-pass side combustion chamber stove. — The two-pass central-combustion chamber stove. — Stove valves and fittings. — Hot-blast valves. — The cold-blast valve. — Stove burners. — Blow-off valves. — Stove castings. — Packing. — Stack for stoves. — The domes of stoves. — The bottom and base ring of stoves. — The checkers in stoves. — The number of stoves per furnace. — Equalizing the blast temperature. — The size and heating surface of stoves.

CHAPTER VI

THE CONSTRUCTION OF THE BLAST-FURNACE STACK 233

The conditions to be met. — Resistance to temperature. — Resistance to chemical action. — Resistance to abrasion by the stock. — Resistance to abrasion by the gas current. — Resistance to pressure. — The constructions adopted. — The hearth and bottom. — The ditch around the hearth jacket. — The tuyère zone. — Cooling plates. — The bosh. — The shaft or inwall. — The stock line and the top of the furnace. — The shape of the top of the furnace. — Thin-lined furnaces. — The Ashland construction. — Firebrick. — The laying of the firebrick. — The filling of the packing space. — Drying the lining. — Bustle pipe, penstocks and blow pipes.

CHAPTER VII

CLEANING AND WASHING THE GAS 285

The outlets from the furnace top. — Downcomers. — Explosion doors. — Dust catchers. — Dust content in gas. — Primary dry cleaning. — Brassert-Whitting whirler. — Brassert modifications of Brassert-Whitting whirler. — Dyblie whirler. — Remarks on efficiency of dry cleaning. — Primary wet cleaning. — Zschocke system. — Duquesne spray tower. — Bian gas washer. — Final wet cleaning. — Thiesen gas washer. — Thiesen disintegrator gas washer. — Schwarz-Bayer disintegrator gas washer. — Fowler and Medley vertical gas washer. — Feld gas washer. — Reco centrifugal gas washer. — Sepulchre gas washer. — Final dry cleaning. — Halberger-Beth gas-cleaning system. — The Kapnograph. — Methods of determining the amount of dust in blast-furnace gas. — Brown dust, moisture, and volume determinator for blast-furnace and other gases.

CHAPTER VIII

HANDLING THE IRON AND CINDER	328
Casting in sand beds. — Casting in chills. — Breaking the iron. — Pig Breaker.	
— Molding up sand beds. — Handling liquid pig iron. — The mixer. — Hot metal ladles. — Casting machines. — Iron trough and skimmer. — Handling the slag by hand. — Slag ladles. — Slag granulation. — Casting the cinder and handling it cold with machinery.	

CHAPTER IX

AUXILIARIES AND GENERAL ARRANGEMENT OF PLANTS	359
The water-supply system. — Pumping machinery. — Stand pipes. — Water mains. — Furnace main connections. — Waste water system. — Compressed air supply. — Electric supply. — Voltage and kind of current to be selected. — The general arrangement of furnace plants. — The distance apart of the furnaces. — The arrangement of the stoves and hot-blast main. — The elevation of the furnace. — The arrangement of the boilers and engines. — Arrangements for the disposal of the iron. — The disposal of the slag.	

CHAPTER X

THE DRY BLAST	383
Early systems of blast refrigeration. — The brine system and its disadvantages. — The power required for refrigeration. — Total heat and entropy curves for air and vapor. — Possibilities of improvement. — Direct expansion. — Two-stage refrigeration. — Regeneration. — Two-stage refrigeration and regeneration combined. — The Carrier system. — The advantages and disadvantages of the precompression and post-compression systems.	

INDEX	407
-----------------	-----

BLAST-FURNACE CONSTRUCTION IN AMERICA

INTRODUCTION

FUNDAMENTAL CONDITIONS—DEFINITION OF BLAST-FURNACE— CLASSIFICATION BY FUELS USED—ESSENTIALS OF PLANT

IRON is one of the most common elements in nature. Geologists state that it comprises about 4.4 per cent. of the earth's crust and that there is strong proof that the whole interior of the earth below a depth of a few miles is composed of iron. The vast segregations which have gone on throughout geological time have resulted in concentration of iron to all degrees from the lowest up to 72 per cent. The concentration never exceeds this degree (Fe_3O_4) for the reason that iron is unlike most other of the useful metals in one important particular. It is seldom or never found native on the earth, except in the form of meteorites which have fallen from space.

This is in consequence of the great affinity of iron for oxygen, with which it will unite under almost all conditions of temperature and chemical environment found on the earth. This brings us to the fundamental fact in the metallurgy of iron which distinguishes it from all the other useful metals.

Its only ores are its oxides. The sulphides are probably the most important ores of the other useful metals but sulphide of iron is not regarded primarily as an ore of iron but only as an ore of sulphur, partly because its sulphur value is greater than its iron value and partly because the blast furnace cannot produce good iron from material containing much sulphur.

When the sulphur is burnt off for conversion to sulphuric acid the iron takes up oxygen to replace the sulphur and becomes an oxide. These artificial oxides then become iron ores under certain conditions and with certain limitations which will be discussed later. But the use of iron sulphide as iron ore either by burning the sulphur off to waste, or directly in the furnace, as is so commonly done with the sulphides of other useful metals, is entirely unknown in the metallurgy of iron.

It is true that carbonates are important sources of iron in Europe, but their carbonic acid is not strongly held and before they are charged into the furnace it is driven off by an oxidizing roast which converts

the resulting ferrous oxide FeO to ferric oxide Fe_2O_3 . This reaction takes place so easily that it even occurs slowly under ordinary atmospheric conditions, but with the slight modification in that case that the ferric oxide takes up water of combination and becomes limonite.

More than 90 per cent. of the world's production of pig iron is derived from ores which occur in nature as oxides and the remainder comes from the roasted carbonates and the ferric oxide or "pyrite cinder" derived from the sulphides.

From the point of view of the blast-furnace, therefore, it is correct to say that the only ores of iron are the oxides.

The removal of the final traces of oxygen from iron is so difficult that it can commonly only be done with an expensive gas like hydrogen or methane or by solid incandescent carbon and as the latter is commercially so much more available we may say that industrially iron is reduced only with solid carbonaceous fuel.

Fundamentally then the metallurgy of iron consists of the reduction of the oxides through the use of solid carbonaceous fuel. This operation is carried on to the extent of a few hundred tons per year in the Catalan forge and to the extent of some sixty or seventy million tons in the blast-furnace, which, therefore, constitutes the foundation of the iron industry.

The blast-furnace is a shaft furnace, the "high-furnace" of France and Germany, and takes its English name from the fact that the air to support combustion must be forced into it under pressure because of the resistance to the passage of the combustion gases offered by its high shaft filled with material. It became, therefore, a "blast" furnace as opposed to a draft furnace, which obtains its air through chimney draft.

The blast-furnace is historically the outgrowth of an attempt to utilize the waste heat of a "low furnace" or Catalan forge so as to reduce the fuel required for the latter and is probably the first industrial application of what is called the counter-current principle.

This may be defined as a method of transmitting the properties of one mass of matter to another by causing the two masses to travel past one another in opposite directions in intimate contact. This process leads naturally also to continuous as opposed to intermittent operation, one of the great desiderata of industrial processes.

This practice of superposing a shaft on a hearth has so long and so universally prevailed in the iron industry that it has caused us to overlook one of the most important facts concerning the blast furnace and one to which we shall have occasion to revert many times; namely that it is an apparatus in which we have merged two distinct processes. First, the reduction of iron oxide to metallic iron. Second, the melting of the reduced material.

The deep fire necessary for melting the "iron sponge" or reduced iron in a reducing atmosphere (without which it would instantly become oxidized again) was not unlike a gas producer in its construction and operation, and consequently discharged a hot gas rich in CO.

The utilization of this heat was the object sought by those early unknown pioneers who added the shaft above the low hearth or Catalan forge, increased the blast pressure to suit, and so transformed it to the blast-furnace.

The fuel economy desired was obtained to such an extent that the low hearth declined to a position of insignificance, although the change brought many other changes not contemplated by the pioneers, some of which were not to their liking.

Most of these must await discussion in subsequent chapters, but one was vastly important because it made a radical alteration in the character of the product, and in the process. The original product was tough and pasty, and could not be melted but could be "wrought" directly under the hammer, while the product of the improved furnace could not be worked under the hammer, either hot or cold, passing immediately from the liquid state in which it could be "cast" or poured to the brittle solid state. Hence the names of the two principal varieties of iron, "cast" and "wrought."

The production of the iron in the liquid condition contributed further to the continuity of the process since the iron could be allowed to gather in a pool at the bottom of the furnace instead of requiring to be worked up through the fire at intervals in lumps or "louns", with fire tools; and the subsequent introduction of a fresh charge of ore.

The shaft-furnace along with these advantages brought a requirement of far-reaching importance. The column of stock must be penetrable to a considerable gas volume at a reasonable pressure. This requirement is just as important to-day as it was in the early day of which I have spoken, though it must be confessed that our ideas of a "reasonable pressure" have undergone great changes.

This penetrability of the stock column may be seriously if not fatally impaired by either of two conditions.

First, the presence of tarry or sticky matter which would fill up the interstices of the charge and make it practically gas-tight.

Second, great fineness of the charge, either of the ore or of the fuel. Moreover, the fuel is subject to a certain solvent action by the gas as will be described later, and this is more active in proportion to the fineness of the fuel so that serious loss occurs if the latter be too fine.

The two principal fuels available, wood and bituminous coal, in their native condition both contain tarry material, generally in important quantities. The vast majority of their varieties are, therefore,

not adapted to use as furnace fuels without preliminary treatment to drive off the tar, so that this condition is industrially of paramount importance.

We can now combine all these necessary conditions to form a fundamental definition as follows:

The blast-furnace is a vertical shaft-furnace blown with air under pressure for reducing iron from its oxides and delivering it in a liquid condition. Its fuel must be not only solid but in lumps of considerable size and must be sufficiently free from tarry components to permit the passage of the gas resulting from the combustion in the hearth.

Additional requirements. — We have given a definition of the fundamental requirements of the blast-furnace. To these may be added two more, which are necessities in the case of more than 99 per cent of the iron produced.

First, the slag must be sufficiently fusible to run freely from the hearth at a temperature easily attainable.

Second, the blast must be warmed before being delivered to the furnace.

The single exception to these two conditions occurs in the case of furnaces making cold-blast charcoal iron of which probably not over twenty or twenty-five thousand tons per year are produced out of a total of some thirty-five million tons in the United States. In this case the temperature attainable is very low and in consequence the slag is not heated hot enough to run freely and has to be removed from the furnace with the assistance of mechanical means such as slag-hooks, etc., or, if it comes from the furnace without assistance, it chills before going more than a few feet and is accordingly troublesome to remove.

Leaving out of account this very small percentage, all blast-furnaces are blown with blast heated from 500 deg. to 1400 deg. F. and their slag is heated to a degree sufficient to enable it to run from the furnace without assistance and far enough to reach some convenient means of ultimate disposal. The heated blast was introduced by the Englishman, Neilson, about 100 years ago, and it has made possible the modern development of the blast-furnace because the velocity of combustion of the fuel is so greatly augmented by preheating the blast, and the continuity of the operation has so increased by raising the molten iron and slag well above their fusion points, that outputs have been increased almost a hundredfold since.

Characteristics required of the fuel. — In addition to these fundamental requirements of a blast-furnace fuel, that it shall not be tarry and shall be in lumps, there are others of nearly equal importance.

The three characteristics next in importance to those mentioned are first, purity, particularly freedom from sulphur and phosphorus.

Second, porosity or ratio of surface to mass. Third, physical strength or resistance to crushing.

Freedom from sulphur and phosphorus.—The reason for the importance of this requirement is that next to carbon these two elements exert the most important influence of any of the common constituents in steel, both being destructive of quality if present to an extent greater than one-tenth of one per cent. If present in the pig iron of which steel is made they cannot be eliminated at all when certain processes are used, and in the others only with increased difficulty and expense. In foundry irons phosphorus is not objectionable within certain limits, but sulphur is almost as much so as in steel, in all ordinary practice.

The blast-furnace may be so operated as to remove the sulphur in the charge but only with increased cost for fuel and flux and with decreased output and in some cases with reduced quality.

For these reasons sulphur in fuel is always bad and progressively worse as its amount increases, although its removal is possible.

This is not the case with phosphorus, virtually all of which present in the charge goes into the pig iron, in normal operation.

Phosphorus in the fuel, on the other hand, may not be objectionable in any given quantity for certain iron, but if objectionable is prohibitive of the use of that material because its removal in the blast-furnace is impossible.

Porosity.—The importance of this quality of the fuel comes from the fact that the velocity of combustion of carbon in air is not infinite but limited. Only a limited amount of carbon per unit of surface exposed can combine with oxygen, no matter how favorable the conditions, and in order to secure the rapid combustion necessary to produce high output from a given size of furnace, much surface must be exposed by the fuel.

This cannot be done by reducing its size and so increasing the ratio of surface to volume and mass, except to a very limited degree for reasons already explained, and high combustion velocities can, therefore, only be obtained with porous fuels.

The porosity also has a direct bearing on the volume of a given weight of fuel, and this also will be shown subsequently to have an important influence on the operation of the blast-furnace.

Physical strength.—This is important because without it, no matter how large the lumps of fuel may be initially, they are broken by the superincumbent weight of the charge column as the coke descends into the furnace and we have that condition of fineness of fuel which is so objectionable.

On account of the fundamental effects on the operation of the furnace and the quality of the iron caused by these chemical and physical variations in their fuel, furnaces and the irons they produce are com-

monly and quite properly classified by the fuels used. These are in the order of their importance as follows: Coke, charcoal, anthracite, raw coal.

The magnitude and components of the plant.—The iron blast-furnace is now probably the largest industrial apparatus in use, not only in size of plant, but in the quantity of raw materials consumed, and output. Furnaces have often been built which produced 600 tons of iron per day, but modern practice tends to slightly smaller units, furnaces now being built only for an output of about 500 to 550 tons per day; but this is maintained as an average output for months and years together.

To produce a ton of iron under favorable conditions requires about 2 tons of ore, $\frac{1}{2}$ ton of flux, 1 ton of fuel and about 4 tons of blast; greater quantities are required when the conditions are less favorable. With each ton of iron is also produced about $5\frac{1}{2}$ tons of waste gases and about $\frac{1}{2}$ ton of slag, the latter, as well as the iron, being handled in the liquid condition. For a 500-ton furnace we have, therefore, to handle every twenty-four hours about 1700 tons of solids, 750 tons of white-hot liquid and 4800 tons of hot gases (blast and waste gases together).

To do this on an industrial scale and with a labor cost amounting in good practice to less than 50 cents per ton, a great plant is necessary. Such a plant must contain the following parts: First: The shaft-furnace itself, through which the entire mass of material just mentioned passes, the solids passing down to the liquid condition at the bottom and the gases upward through them. Second: Means for handling the raw materials, ore, fuel, flux, proportioning them properly and delivering them in certain accurate and positive relations into the top of the furnace. Third: Means for raising the atmospheric air to a pressure sufficient to force it through the furnace in the quantity desired. Fourth: Means for heating this supply of air uniformly and regularly to the temperature desired. Fifth: Means for handling the molten iron on its discharge from the furnace and turning it into a commercially salable product. Sixth: Means for removing the slag from the vicinity of the furnace. Seventh: Means for removing the gases from the top of the furnace and (as these gases are a valuable fuel) for leading them to those portions of the plant where they can supply the energy for compressing the blast and heating it. There is an eighth requirement not embodied in our fundamental definition, but which has become an absolute necessity notwithstanding; a supply of water for cooling certain parts of the furnace and preventing the intense heat inside from destroying the structure.

CHAPTER I

HANDLING THE RAW MATERIALS

THE average output of blast-furnaces has increased in little more than a generation from about thirty tons per day to about five hundred tons per day. This great increase has occurred simultaneously with a decrease in the supply of labor relative to the demand, and a great increase in its cost.

These two circumstances have brought about great changes in the methods of handling the raw materials for pig-iron manufacture. These materials are so generally ore, coke and limestone, that unless definitely stated to the contrary, they will be meant when the term raw materials is used. In furnace parlance these are also known under the name of "stock," and the building in which the supply is stored to cover irregularities in daily receipts is known as the "stock house," a term which has survived the existence of any actual house.

The prime condition for successful operation of the furnace is that it must be run continuously. This is a fact that it will be necessary to emphasize many times in subsequent chapters. This term means literally twenty-four hours a day, seven days a week, fifty-two weeks a year, and for several years at a stretch. To enable furnaces to be operated in this way a supply of raw materials must always be on hand, in spite of interruptions to transportation and other conditions which make regular daily receipts impossible. The first and obvious one of these conditions is the occurrence of Sunday, when transportation is always partly, very often wholly, suspended. This makes it indispensable to have a supply of raw materials large enough as a minimum for two or three days' run, and rising as high as a six months' supply in many cases.

The small charcoal furnaces of the old days were generally built close alongside of a very steep hill, and had a bridge running from the top of the furnace over to a leveled yard or space on the hill, served by a wagon road with an approach long enough to permit the hill to be surmounted. All raw materials were delivered by team into the stock house built on this level space, and unloaded, at first by shoveling from the wagons, later by wagons with loose bottoms, which could be pulled out, one board at a time. These materials were shoveled by hand into filling barrows, which were then wheeled onto a platform scale set for the correct weight of the given materials. The weight

was adjusted by shoveling into or out of the barrows to make the balance correct, and the barrows were then wheeled across the bridge to the top of the furnace and there dumped. Of other equipment besides shovels, barrows and scales there was none. The number of men employed was not very great because the quantity of material handled in a day was small. Fifty years ago it probably did not average much over one hundred tons in twenty-four hours, and as a small number of men could handle this amount of material, equipment would not have been needed had it been available, because the saving would have been too small.

With the great increase in the size of the units, conditions became more and more difficult. The gangs of men required to fill a furnace grew to be large. The work was hard and it was very difficult to maintain full gangs. It must be borne in mind that no delays could be tolerated, a short suspension of filling would let the furnace get "down," which would probably be reflected in poor iron or in some other form of bad furnace work the next day.

More than 80 per cent. of the iron produced in the United States is made from ores mined in the Lake Superior region and transported wholly or partly by water to the points of consumption. Navigation on the Great Lakes is open nominally seven months, but actually only about six in each year. Therefore furnaces which derive their ore supply from this region are under the necessity of having on hand a six months' stock of ore at the close of navigation. If the furnaces are some distance removed from the receiving port of the ore, the latter may be stored on the docks or at storage yards maintained by the railroads. But the best practice increasingly tends toward shipping the ore directly to the furnace plant, and storing it in an ore yard devoted to that exclusive purpose, and not infrequently equipped with powerful and expensive machinery for putting the ore into the stock pile and reclaiming it as needed throughout the year.

A plant of four furnaces, each of a daily capacity of five hundred tons of metal, is not a large one as furnace plants go to-day, but such a plant consumes four thousand tons of ore per day, or 1,460,000 tons per year, and all of this must be stored during six months or less, and half of it, say 750,000 tons, must be reclaimed from storage during the six months which includes the winter weather, and principally in the severe climate which characterizes the central district of the United States. As it is characteristic of the Lake Superior ores to carry from a minimum of five or six, to a maximum of twenty-two or twenty-three per cent. of moisture, with an average of ten or twelve per cent.; and as this moisture is not combined with the ore, but only held by it in the shape of moisture, these great stock piles freeze to a depth of several feet, and the ore being soft and plastic, like clay or sandy

loam in most instances, the frozen mass is exceedingly hard. Machinery well able to handle the material in its unfrozen condition would be unable to stand the service on frozen ore for the briefest period. This adds another very severe condition which must be met in handling the raw materials for iron manufacture in a preponderating portion of the industry.

Stock hoisting.—The first change from the primitive arrangement I have described was the introduction of power hoists for taking the material to the top of the furnace. These were of two kinds, vertical and inclined, but irrespective of this, in the majority of cases a platform was used on to which the barrows were rolled by men at the bottom. The platform was then hoisted, whether vertically or on an incline was a matter of detail, and men at the top, known as top fillers, took the barrows off the car, distributed them around the top of the furnace and dumped them.

The introduction of power hoisting as a substitute for the bridge method of bringing the material to the top of the furnace was necessitated by the increase in the height of the furnace from some twenty-five or thirty feet to fifty, sixty and seventy feet. No hill could be found steep enough and high enough to lend itself to filling purposes for furnaces of such heights.

The operation of filling being continuous, and the need for capacity growing rapidly after the introduction of power hoisting, double acting hoists were introduced very early and are used almost universally, with certain exceptions to be noted later. By this means the platforms, cars and filling barrows balance each other on the ascending and descending trips, leaving only the useful load of the charge to be hoisted. This effects the saving of a great deal of power, and permits the use of much smaller hoisting apparatus.

Many styles of hoisting apparatus were tried in the early days of power hoisting, hydraulic, pneumatic, water-balance, and various types of engine-driven hoists were used. Nevertheless this was one of the earliest parts of the equipment to become standardized, and for many years there has been used a very simple type of vertical two-cylinder engine, with cranks at right angles, and the engine shaft geared to the rope drum with either a single or double reduction gear. These engines are not fitted with a link like that used for reversing locomotives and other high-grade engines, but are reversed by running the steam in opposite directions through their ports. One set of openings constitutes the inlet when running in one direction and the exhaust in the other.

In order to operate successfully on this system the valves must be set without "lap" or "lead," the eccentrics being exactly at right angles to the cranks, so that the steam follows the piston full stroke,

and is not used expansively, even to the slightest degree. As a result these engines are very extravagant of steam, using about one hundred and twenty pounds per horse-power as against twelve to twenty pounds for ordinarily good engines in power stations.

In the last ten or fifteen years there has been a growing tendency to avoid this great waste of steam by the use of motor driven hoists, these obtaining their current from generators in the power station,

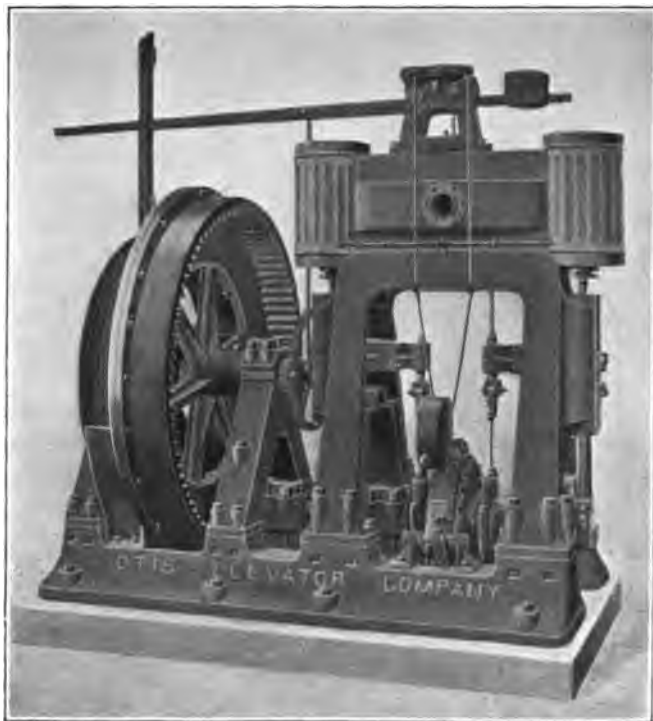


Fig. 1. Steam driven blast-furnace hoist for furnace with vertical hoist tower.

driven by an engine using not much more than a tenth of the steam per horse-power that is required for the hoisting engine.

There are, however, problems of control which have had to be met and which have proven rather difficult. With the large masses of material now handled it is very important that the operation of hoisting be started and stopped gradually to eliminate the excessive inertia stresses which would otherwise arise. These problems have been solved successfully with the steam hoisting engine by the use of supplementary throttles thrown in and out of operation by a cam traveling at a suitably reduced speed. In order to accomplish the same result with the electric hoist, sliding contacts and a great multiplicity of

switches were at first considered necessary, so that the switchboard for such an apparatus was very large, elaborate and expensive.

This problem has, however, been worked out successfully, and such electric hoists are now articles of regular manufacture, as are the steam hoisting engines previously mentioned. Fig. 1 shows a modern steam-driven blast-furnace hoist for a furnace with a vertical hoist tower, where the ropes are led by guide sheaves from the tops of their respective cages to points vertically over the opposite sides of the drum, so that when the rope from one cage is winding up that from the other is unwinding. The cages are thus balanced through the hoisting

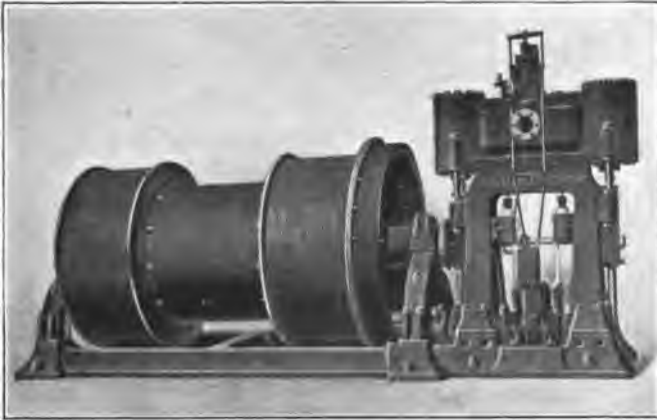


Fig. 2. Steam driven hoist for a skip-filled furnace.

drum rather than directly. This hoist is built by the Otis Elevator Company.

Fig. 2 shows a steam-driven hoist for a skip-filled furnace, in which there are two distinct drums, separated by a suitable distance horizontally so that the center of each drum shall be in the central plane of its skipway. This will be more fully explained in dealing with skip hoists. This hoist is also built by the Otis Elevator Company.

Fig. 3 shows an electrical hoisting apparatus with its switchboard, built by the Lidgerwood Manufacturing Company. It will be seen that the rope drums in this are the same type as that shown in Fig. 2, this also being for a skip-filled furnace.

Hand-filling and filling-barrows. — The system of handling raw materials in barrows was almost universal until the middle of the decade beginning in 1891. Many attempts had been made to eliminate at least a portion of the labor required for handling the great quantity of material needed as furnace outputs increased. But these were either mechanically unsatisfactory, or else their effect upon the work of the furnace was detrimental, in many cases disastrous. The



Fig. 3. Motor-driven joist for a skip-filled furnace.

reasons for this, in so far as they are known, will be given at some length in describing operation; suffice it for our present purpose to say that probably ninety-five per cent. of all the iron made for thirty or forty years previous to the year mentioned was made from raw materials handled in filling barrows. These are so widely known that it seems almost unnecessary to describe them, but for logical completeness a brief description may not be amiss.

These barrows are universally two-wheeled, with at least one of the wheels loose on its axle to enable them to turn corners easily, and provided with stout legs on the rear end, which hold them level when standing. They are dumped by tipping forward on the axle, the wheels remaining stationary when they come against the dumping

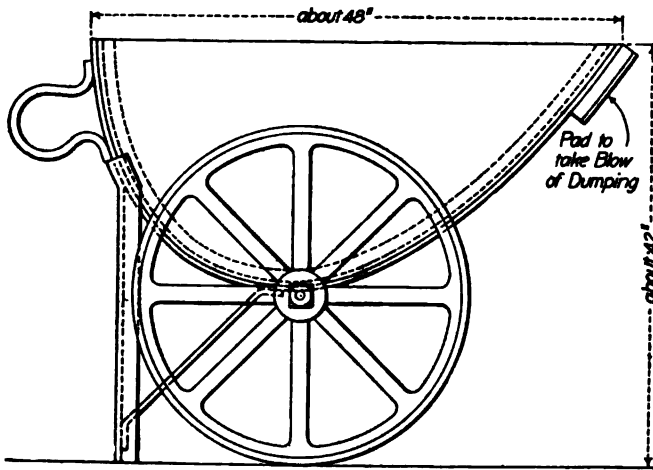


Fig. 4. Ore Barrow.

ring on the top of the furnace. On account of the vast difference in the specific gravity of coke, and ore, or limestone, a different type of barrow is generally used for handling these two kinds of materials. The ore and limestone barrows are as shown in Fig. 4, and the coke barrow as shown in Fig. 5. The latter are much larger and provided with a door in front, which is held shut by a latch, this latch being released from the rear a moment before the barrow is dumped. This construction is used in order to obtain a reasonable capacity for so light a material as coke. These barrows are built of steel plate, very substantially riveted together throughout, as they are subjected to continuous service and particularly to very heavy shocks when they are dumped, the nose of the barrow dropping forward on the iron dumping ring with a hard blow.

In ordinary practice the barrow weighs about eight hundred pounds and can carry a load of about fifteen hundred pounds of ore, but

they are commonly not loaded quite as heavily as this, as they then become too difficult for one man to handle, even on good floors.

The capacity of the coke barrow is roughly one-half as much by weight, so that the same number of barrows of coke as of ore are required per charge, the ore charge weighing normally about twice as much as the coke charge.

The physical labor involved in wheeling the barrows from the stock piles to the foot of the hoist is in ordinary practice roughly the same as filling them by hand. Therefore to dispense with hand shoveling, and continue the use of filling-barrows, is only a half solution of the

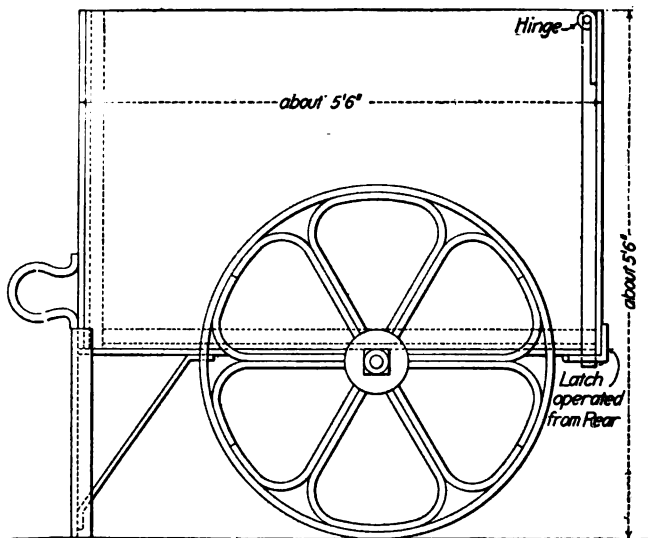


Fig. 5. Coke Barrow.

problem of eliminating manual labor in filling. Moreover, when the barrow system of filling is used it is necessary to have always one, and frequently two or even more men on top of the furnace to take the barrows from the cages to the furnace top, dump them and return them.

This labor is more expensive, man for man, than the labor at the bottom of the furnace, because it does not pay to have a foreman supervise the relatively small number of men required, and yet the operation of dumping, with which they are entrusted, is of the utmost importance, and with hand-filling, slight variations in the method of dumping, more frequently than any other cause, derange the work of the furnace.

For this reason it is necessary to secure a higher grade of labor for at least one of these top fillers by paying higher wages. Another rea-

son for paying higher wages is that the men are under a certain liability to be overcome by the furnace gas when remaining for a long time on top. It is impossible to make the bell absolutely tight and keep it so all the while. Small particles of stock lodge on its seat and hold it open by an almost microscopic amount until the next dumping, when they are swept off, but very likely replaced by similar particles in some other location, so that the bell seldom shuts absolutely tight.

There are other points at which gas can escape, such as the test rod hole and various other places through which the gas will find its way in quantities frequently too small to be visible, but nevertheless tainting the atmosphere sufficiently to overcome men exposed for a long time to this poison, even in this dilute state. This possibility of accident, though real, is small, fatalities in the ordinary course of filling being almost unknown, nevertheless it is sufficient to necessitate a higher scale of wages.

For all these reasons the elimination of manual handling of the stock from the bins to the furnace top was the goal of furnace builders for many years. Blast-furnace engineers were often sure that they could build a top that would give results as good as those of hand-filling, but managers, knowing that they would be held responsible for the operation and that bad construction would not be an acceptable excuse for bad furnace work, were for a long time very chary of using any method of filling of whose results they could not be absolutely sure in advance, and this for a long time meant hand-filling exclusively.

The Duquesne revolution. — In the middle of the decade beginning 1891, furnace outputs had become as high as 400 tons per day in regular operation. The crews necessary to fill them by hand labor with filling-barrows were tremendous. Then, too, the capacity of the platform hoists had about reached their limit, and it became almost a matter of physical impossibility to fill furnaces for any greater output by this means. Accordingly when about 1895 the Carnegie Steel Company decided to build at Duquesne a plant of four furnaces with a capacity of six hundred tons per day each, these furnaces being about twenty-one feet in diameter by one hundred feet high, they determined to strike out on new lines and eliminate altogether hand labor for filling.

M. A. Neeland was then chief engineer of the Duquesne works, and he designed what has since become one of the standard methods of mechanical filling, commonly known as the bucket system. This was a success mechanically and metallurgically and was the beginning of a revolution in the construction and operation of blast-furnaces. It having been demonstrated that mechanical methods could be made to operate successfully on so large a scale, and with an enormous saving of labor, other methods to achieve these ends were soon devised, and

as a result it is probably safe to say that three-fourths of all the iron now produced is made at furnaces mechanically charged.

The plan of eliminating labor wherever possible was carried out in all directions at the Duquesne plant, whose mechanical equipment throughout was the best obtainable at that time. Thus the construction of this plant marks a distinct epoch in the history of the blast-furnace in the United States.

The delivery of the stock to the furnace. — Returning now to the matter of handling raw materials from the stock piles to the barrows, this, as has already been stated, was at first done exclusively with shovels, but when the introduction of railroad transportation replaced the delivery of the raw materials to the plant by team, it was soon found necessary to elevate the tracks on trestles to facilitate unloading the material from the cars.

The cars were at first of the flat-bottom type, but very soon hopper-bottom cars, the prototypes of those in use to-day, were introduced. For these trestles became absolutely necessary. It was then a short step to install bins underneath these trestles, into which the materials could be dumped directly from the cars, and from which, in turn, they could be drawn directly into filling barrows without hand shoveling.

This eliminated probably fifty per cent. of the labor of filling, and, considering the great returns which the investment in bins pays in the form of labor saved, it is surprising that their introduction was not more rapid, but at the time of the Duquesne revolution many plants which considered themselves modern and well equipped were still handling their raw materials largely or wholly by hand. Since that time, however, the use of bins in large plants has become practically universal.

It will be seen that the order in which we have followed these developments, in the hoisting of the material, in its transportation from the stock house to the furnace, and in its delivery into the means of conveyance in the stock house, is the reverse of their logical order. But this is the way the development actually occurred chronologically, and to consider them in this order is perhaps justified on this account.

In discussing the development of mechanical filling, it is now necessary to revert to the subject of the delivery of the ore, for so large a part of the ore in this country is transported by water, and only during a relatively brief season, that this has had profound influence, not only on the handling of the ore at the ports of receipt, but also at the blast-furnaces, because the machinery which was developed for unloading the boats was found almost equally valuable, with slight modifications, at the blast-furnace also.

The conditions of water transportation imposed two difficulties on this traffic. First, the difficulty of unloading ore from the holds of

vessels well below the water line, lifting it to a sufficient elevation and transporting it to a sufficient distance to enable it to be deposited in a stock pile, and, second, the necessity of doing this in the least possible time.

As has so often happened in industrial history, the solution of these difficulties resulted in an eventual benefit of enormous importance to the industry concerned. Less than a generation ago, boats of two or three thousand tons, the largest then in service on the Great Lakes, could be unloaded only by shoveling the ore by hand into tubs, hoisting these with whips, dumping them on the wharf and then wheeling the ore up an incline onto the stock pile. This took vast quantities of labor, and as the men required physical stamina and endurance to stand up under this work there was a limited market from which this labor could be drawn, and as a consequence the supply was always below the demand. This resulted, as it always does in such cases, in making the men to a very high degree arrogant, unreasonable and difficult to manage. This, in conjunction with the high wages it was necessary to pay them, made the unloading process very tedious and expensive.

During the decade beginning 1881, Alexander E. Brown began to apply his brilliant engineering ability to the problem of performing this work mechanically. His efforts met with the highest success, and other engineers, following in the path which he had blazed, developed still further the possibilities of mechanism in such work, so that while in 1885 it took about three days to unload a vessel of three thousand tons, and cost about twenty-five cents per ton, it is now possible to unload vessels with machinery designed for this purpose in a shorter time than their cargo can be spouted into them from bins on the docks at the Upper Lake ports, and at a total cost for labor, power, maintenance, interest and amortization on investment of not over four cents per ton.

In the summer of 1912 a steamer containing something over thirteen thousand tons docked at 1:15 and was unloaded and had cleared for the Upper Lakes at 4:35 on the same afternoon. Three hours and twenty minutes to remove thirteen thousand tons of material! Probably not over twenty-five men all told were employed on the task, so that the labor cost was almost negligible. This was a record at that time, though it may have been beaten since.

Ore handling machinery. — On account of the vast influence of the machinery developed for unloading vessels on the problem of stockpiling and reclaiming ore at the blast-furnace, it will not be amiss to illustrate here some of the equipment by which these results are achieved. Fig. 6 shows a fast plant, designed and built by the Brown Hoisting Machinery Co., and may be considered the legitimate development of

the first mechanical equipment built for this purpose by the same company twenty-odd years ago.

Where greater stocking capacity is required than the fast plant trolley travel will cover, traveling bridges are used, as shown in Fig. 7. In these the trolley travels on the straight member of the bridge, which is carried on the two traveling towers shown. One of these runs on a double set of rails near the dock front, spanning one or more standard gauge tracks, the other on a single rail at the rear end. The bridge is pivoted to the towers or legs so that it can be slewed at a considerable angle. The runway is carried beyond the line of the traveling legs on cantilevers, the outer one of which is hinged so that it can be raised



Fig. 6. Brown-hoist fast plant.

up out of the way to permit the bridge to pass the spars of vessels. Equipment of this type is used particularly where the furnace plant is at the lake front. Where the stocking capacity required is so great as to necessitate the employment of bridges and where rapid unloading capacity for the vessels is also required a combination is made of the two styles of equipment. Several fast plants remove the ore from the vessels and dump it within reach of the bridge, which picks it up again and stocks it as required, as shown in Fig. 8. This system will be described more in detail in conjunction with the Hoover & Mason and the Wellman-Seaver-Morgan apparatus.

Fig. 9 shows in diagrammatic style a Hoover & Mason unloading and stocking apparatus. This consists of two distinct parts. First, a gantry crane with cantilever extensions; one side of it is carried on wheels running on the top of the left hand wall of the ore trough, the other on wheels running outside the railroad tracks close to the dock



Fig. 7. Brown hoist traveling bridge.

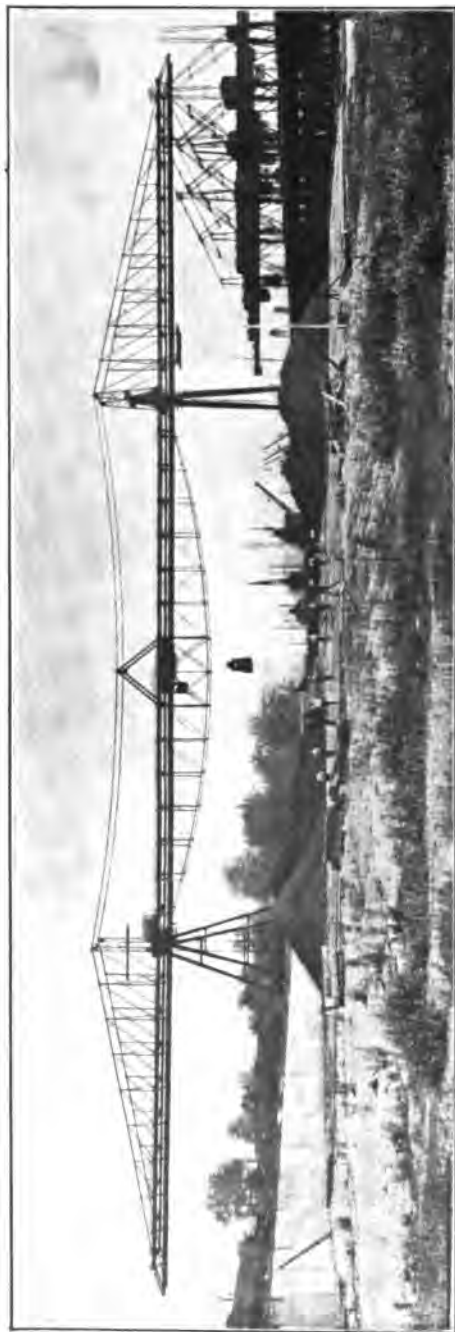


Fig. 8. Brown hoist bridge with fast plants in background on the right.

face. This gantry supports a horizontal runway for a trolley from which hangs a grab bucket, shown in its open position after descending into the ship's hold, at the extreme right.

The method of suspension of this grab bucket is such that it may be rotated at any angle, for the reason that it can only go through the hatches when turned with its long axis parallel with the hatch. But in order to reach out beyond the hatch line and get the ore between the hatches, it is necessary for it to be able to rotate so that its long axis is at right angles to the line of the hatch.

The operation of unloading is carried on as follows: The grab bucket is lowered into the ore, closed, turned parallel with the hatch and elevated to a position alongside the cab hanging from the trolley. The whole trolley is then traversed back to one of two positions and there dumped. The first position is just to the left of the center of the gantry; the other on the left-hand extension of the cantilever outside the gantry. In the first position it discharges into a small hopper and from there the ore is loaded into railroad cars for direct shipment. In the second case it discharges into a concrete trough, from which the ore is re-loaded by the second portion of the apparatus.

This consists of a traveling bridge one hundred and eighty-seven feet from center to center of supporting legs, with cantilever extensions on each end, running its total length up to four hundred and ninety-five feet. This bridge is also equipped with a trolley and grab bucket, the later be-

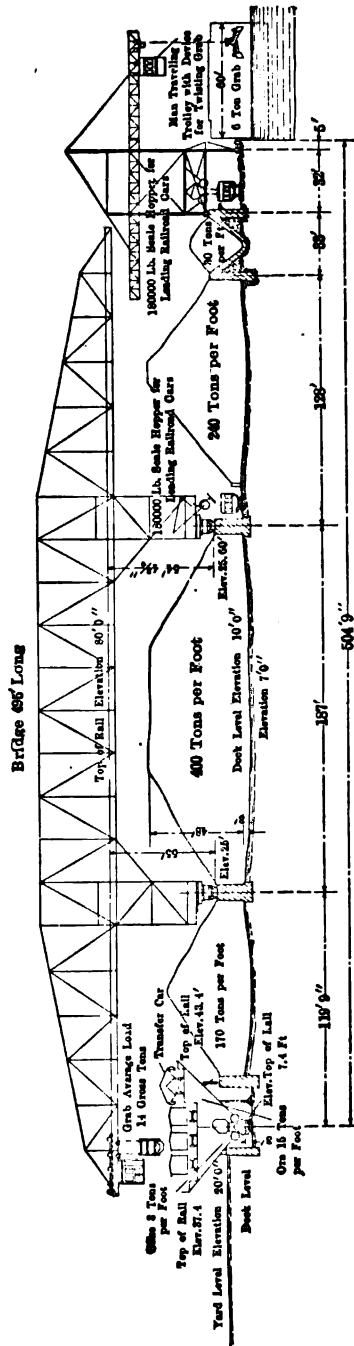


Fig. 9. Hoover and Mason unloading and stocking apparatus.

ing of more than twice the capacity of the one which goes into the ship's hold, which is of six tons' capacity, the one on the main bridge being of fourteen tons.

This bridge travels on tracks laid on concrete walls raised up well above the level of the ore yard, so that the ore will not run down on the tracks even when the yard is filled about to its capacity. The trolley and grab bucket on the main bridge use the ore in the trough as a source of supply, and taking it out of this trough carry it back to any one of the three piles under the three portions of the bridge and there dump it.

The drawing is so plain as not to need much detailed explanation. Means are provided whereby ore may be shipped out by rail from two or three points. At the left of the drawing is the bin system for the furnace itself, this plan having been prepared for a furnace plant located just back of the dock line on the lake front, but a plant of the same general type would be used if the ore were merely stored in the yard and shipped out as required through the winter.

It will be seen that the gantry unloaders are relatively inexpensive as compared to the main ore bridge, and it is therefore commonly possible to have five or six of these all working on a vessel at the same time, and delivering their ore into the concrete trough. The large bridge follows these and keeps the trough sufficiently clean for them so that they are free to dump in it when they move, as required by the contents of the hatchways, etc., thus the unloaders can be devoted to the purpose of unloading without much consideration of the question of ultimate disposal.

The bridge, on the other hand, is an extremely expensive apparatus, and, being many times heavier than the gantries, cannot be moved back and forth as they are, though it can move with sufficient ease to follow them at intervals and keep the ore trough free for them. By this combination rapidity of unloading is secured without excessive expense for long-span bridges.

The latest developed apparatus for unloading is that brought out by the Wellman-Seaver-Morgan Company, and named for its inventor, Mr. George Hulett, the Hulett unloader. A diagram showing this in conjunction with an ore bridge is shown in Fig. 10. This apparatus is equipped with a grab bucket, a modification of the old clam-shell bucket, but with two important differences from the machines of Brown and Hoover & Mason.

First, the bucket, instead of being suspended by ropes, is carried at the lower end of a rigid leg.

Second, the grab bucket, instead of having both jaws symmetrical, as is the case with the suspended buckets, has one jaw provided with a horizontal traversing motion, so that after it is opened, with the

jaws swung up into the vertical position, it can be extended several feet horizontally, and by being lowered into the ore in this position and then drawn in, serves to pull the ore toward the center of the bucket with a motion exactly like that of a gigantic hoe.

The operator rides in a small chamber in the stiff-leg which carries the grab bucket. This is raised and lowered by a walking beam supported on trunnions, which are carried on a truck provided with means for traversing itself back and forth in the plane of the walking beam, that is in a plane at right angles to the dock line. The track on which the truck or trolley moves is carried by a traveling gantry bridge running on a pair of tracks, one close to the face of the dock, the other some distance inshore, as shown. The column, or stiff-leg, which carries the grab bucket, is held in a vertical position by a parallel motion irrespective of the angle of the walking beam.

The grab bucket and part of its load are counterweighted at the opposite end of the walking beam to reduce as much as possible the amount of power required for raising it and to facilitate its control.

In operation the walking beam is tipped to lower the grab bucket through the

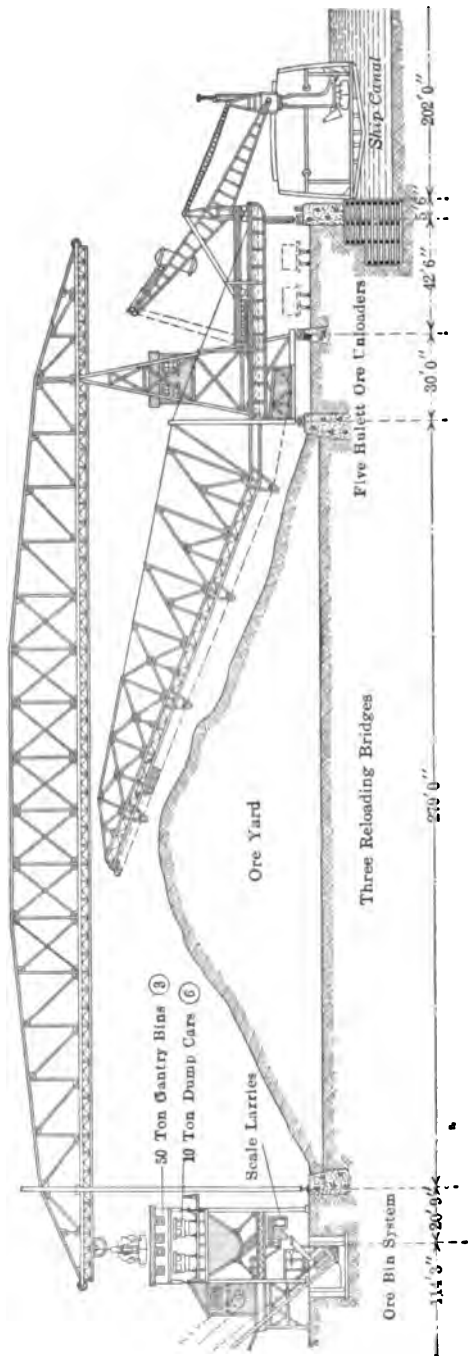


Fig. 10. Hulett unloader in connection with ore bridge.

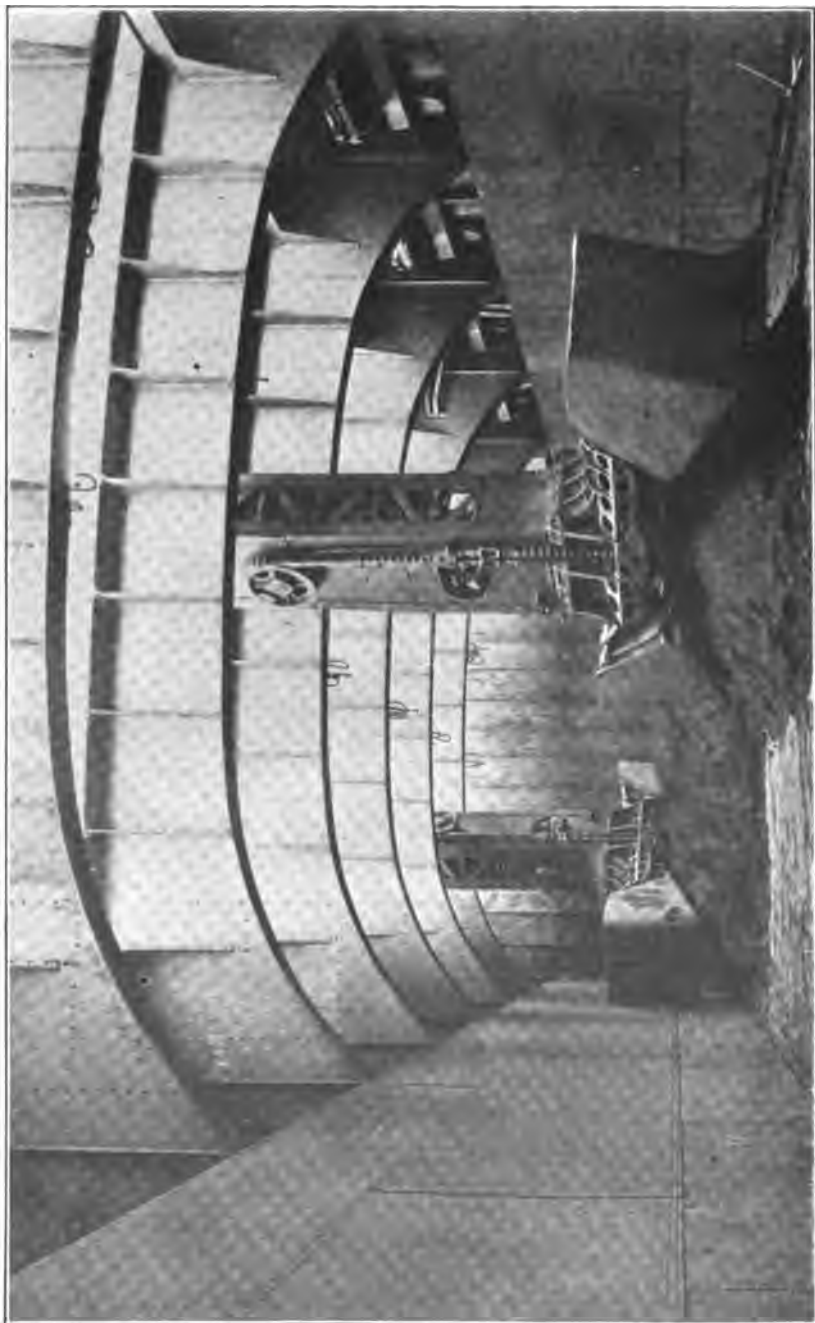


Fig. 11. Hold of vessel with the grabs of two Hulett unloaders at work cleaning up the floor.

hatch, the stiff-leg is then rotated to throw the longer arm of the grab bucket into any desired position, and if only a small quantity of ore remains in the hold at this location, the long arm of the grab is then used to pull several piles of ore together so as to make an approximately complete load for the grab, which it then picks up, so that it always goes up from the hatch loaded to its capacity. This capacity is very large. For a time ten tons was considered to be the limit, but several machines are now in successful operation with fifteen-ton grabs. After the grab is closed it is rotated to coincide with the line of the hatch and raised up through the latter and the truck which carries the walking beam is then traversed inland until the grab comes over to one of two or three alternative points of discharge. Two of these deliver directly to railroad cars on tracks running between the legs of the Hulett. The other is a small retaining hopper running on wheels which travels on the landward cantilever extension of the machine.

In case stock piling is to be done the grab bucket discharges into this traveling hopper, which then runs out on the cantilever and discharges on the stock pile. If more stock pile room is desired than can be reached by the cantilever, a traveling bridge is brought into play precisely as described for the Hoover & Mason apparatus. The photograph (Fig. 11) on the preceding page shows the hold of a vessel with the grabs of two of these unloaders at work cleaning up its floor. No hand work has been done in this hold, yet it will be seen that the floor is almost as clean as if it had been swept, except for the piles on which the buckets are still operating.

Fig. 12 shows one of these Hulett's complete, though not provided with a long cantilever extension, but with a bridge in the background to do the stock piling.

Fig. 13 shows three Hulett's working on a vessel with the piles of ore at their landward ends, and the outer end of the bridge, which is making the stock pile, in foreground. Fig. 14 shows four Hulett's working on a steamer with stocking bridge behind them.

The absolute control of the mechanism which the operator exercises by having it rigidly supported instead of swung, and by the fact that he himself is immediately above the bucket and can see to control its movements accurately, gives this machine advantages in handling bulk cargoes not enjoyed by any other type of machine. One of these advantages is that this accurate control of the grab bucket enables the operator to avoid striking the bottom of the hold severe blows with the bucket, as frequently happens with older types of apparatus.

In reclaiming the ore from the stock pile for use at the furnace the operation is very similar to that of stock piling. But in this case also it is necessary to provide some more easily moveable means than the



Fig. 12. Hulett complete.



Fig. 13. Three Hulets on a vessel, with the bridge making the stock Pile.

bridge itself for carrying the ore from the bridge to the point of consumption. It will be readily understood that there are always several,

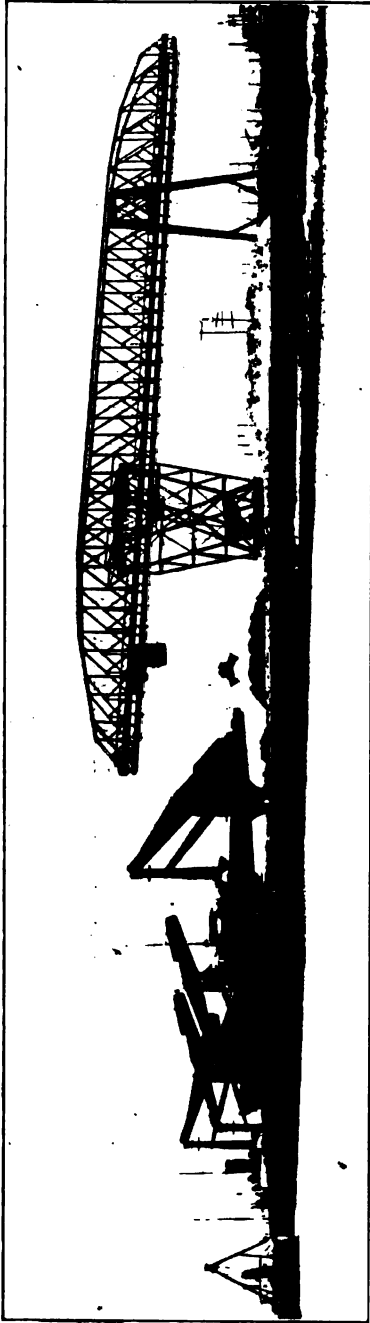


Fig. 14. Four Hulett's working on a steamer with the stocking bridge behind them.

and often very many varieties of ore in the stock pile, and on account of the great difficulty in keeping these separated, the same kinds of ore are always piled together, so as to make the individual piles as few in number and as large as possible.

When any given kind of ore is desired for the furnace therefore, the ore bridge is moved over this pile and the grab bucket set to work on it. At the furnace or discharging end of the bridge it spans at least one and generally several tracks. Each traverses the tops of the bins from which the immediate supplies of raw materials are drawn. On one or more of these tracks runs a drop-bottom transfer car, generally driven by an electric motor under the control of its operator. Such a car can carry fifty or more tons of material at a trip. The distance from the bridge to the bins where the ore is needed being only a few hundred feet, it can readily run back and forth from bridge to bins, and serve the bridge about as fast as the latter can reclaim the ore.

Many variations of this general plan of operation have been worked out. In some places removed from the Lakes the ore is received in drop-bottom cars, which are dumped from trestles, and the ore then reloaded as needed, either by taking the furnace-filling equipment direct to the stock pile and there loading

it by hand, or by reloading the ore with clam-shell buckets, operated by locomotive traveling cranes, loading it into cars on the trestles, taking these to the bins and dumping.

Car dumpers. — Plants removed from the lake shore must, of course, receive their ore by rail, and the enormous quantity to be



Fig. 15. Car dumper.

handled in the relatively brief open season has made desirable in some cases a greater speed in dumping than can be secured even with the modern drop-bottom type of ore car.

To meet this condition an apparatus called a car dumper has been applied at some plants. This apparatus has been built in two styles, stationary and moveable. The moveable type is greatly to be pre-

ferred, because when a stationary dumper is used some style of transfer car is needed to carry the ore from the car dumper to the stocking bridge, which must stand in the location at which it is desired to stock the ore. With the traveling type of car dumper this is not necessary. The car dumper is moved along on its own tracks, just in front of those carrying the rear end of the bridge, and the car when dumped delivers the ore to the exact spot where it is most easy for the bridge to pick it up.

The general appearance of the car dumper, just back of the retaining wall of the ore yard, with a car standing in it, is well shown by the photograph, Fig. 15.

This apparatus can easily dump one hundred and fifty cars per day of ten hours, and most of the cars used in this service carry about fifty-five gross tons. It will be seen that the amount of material which can be handled through it in a given time is enormous.

In spite of the enormous capacity and great efficiency of these machines for the purpose intended, it may be doubted whether very many plants require the dumping of so vast a quantity of ore in a given time as to compensate for the heavy interest charges on the investment involved in one of these machines, especially in those cases where the ore yard is provided with elevated tracks from which dumping may readily be done.

In such a case the amount of labor involved in dumping the desired number of cars of ore from modern drop-bottom cars is not great, and its cost in all probability does not offset the interest and amortization charges on a car dumper.

At those plants in which the location of the ore yard is relatively high, and it is impractical to provide an elevated dumping trestle, the car dumper undoubtedly furnishes the best solution of the problem when considerable tonnages are to be handled.

Power used. — Various kinds of power have been used from time to time for operating the various types of ore-handling machinery, described and illustrated above, but it is safe to say that at the present time no power except electricity is seriously considered for this service under any ordinary conditions. This is supplied either from trolley wires or from sliding contacts, like a third rail, parallel to the track, as the circumstances may require.

Whether alternating or direct current be preferable is a matter of some discussion among experts in this field, but in the majority of cases direct current at 220 volts is used, because of the superiority of control which the direct possesses over the alternating, and because with this kind of current dynamic braking can be used in addition to mechanical brakes, for retardation of the moving parts. This can not so easily be done with alternating current.

Each plant presents ore-handling problems of its own, and in each case the problem must be worked out on the basis of the conditions to be met. Enough has been said to give a substantial idea of the general outline of the operation.

Design of bins.— We may now consider the bins which serve for storage of the raw materials going immediately into consumption.

These bins are of many types, bins having had a development covering many decades. Substantial and well designed wooden bins were in use at a few plants thirty, forty and fifty years ago. But the great storage required for modern plants necessitates one and frequently three or four tracks on top of the bins, all of which must carry the most heavily loaded railroad equipment. This, with the excessive maintenance of wooden structures, has gradually forced the introduction of steel bins, built as an integral part of the structure which supports them and the railroad tracks at the same time. Recently concrete bins also have been introduced.

It is useless to try to illustrate all the types of bins which have been used, and I shall therefore show only four of the best known types, three of which are brought out by the three concerns whose ore-handling machinery has previously been described.

It is necessary to explain that at the large modern plants where equipment of the highest type is used, mechanical filling is now practically universal, and these bins are not therefore designed to discharge into filling barrows, but into the modern successor of the filling barrows, the scale car.

The design of gates for bins is a matter, the difficulty of which in practice is as great as its simplicity appears to be on cursory examination. The material to be handled is irregular in size, irregular in shape, rough, as likely as not to be sticky, and more likely than not to have its coefficient of friction greatly altered by change from dry to wet. If the gate opens and closes from above, guillotine fashion, it may just happen to catch the largest lump passing, which may be too strong to be crushed, and holding the gate open will leave room for a rapid flow of finer material under it. If the shape of the chute be not right the material will jam and bridge, exercising apparently almost human, not to say devilish, ingenuity, in building an arch which quickly cuts off the flow of material from the bin, and which cannot be broken outward because the material is under compression, nor inward except with the greatest difficulty because the pressure of all the material in the bin lies against it.

More than one case is on record where an engineer or furnace manager has designed a new type of gate for a bin, taken a guest out to see how beautifully it operates, and then had it fail so completely that the filling barrow, or even the scale car, would be buried up because

the material could not be shut off when the "improved" gate was brought into play.

Even if these fundamental difficulties be overcome great care is necessary in placing the spouts on the bins and bringing them sufficiently close together so that material does not build on the space between them and in time almost fill up the bin. This may seem like an extreme statement, but I have seen bins of the very best construction and most carefully designed, which looked to be full of ore, but on closer examination two holes, three or four feet in diameter, were to be seen running down from the top to the two chutes below. These holes would represent almost the only free-flowing capacity of the bin. The ore being plastic and sticky, had built up upon the base of the bin and the bridge between the spouts, until the capacity of the bin was almost gone. This is likely to happen to some extent with any design, and the only way to meet the situation is to dig the bin out at frequent intervals, as the rapidity with which the ore builds is increased as it gets a larger and larger foothold.

It was with the object of overcoming these various difficulties and furnishing bins whose flow would be under the absolute control of the operator that the four designs now to be described were brought out.

Taking the designs of the three builders mentioned in the same order as before, Fig. 16 shows a "parabolic" bin designed by the late Alexander E. Brown, of which the principle is taken from the fact that when a liquid or semi-liquid is suspended in a trough of flexible material, the cross section assumed by the trough is a parabola, therefore by giving the bin this shape, stresses tending to deform it are eliminated, and only its weight needs to be considered. These bins are suspended from heavy girders, which in turn are supported by steel columns. The complete parabola at the left is for ore. The incomplete one of greater width, on the right, joined to the ore bin at the left, is for coke.

The spouts on these bins with their gates in the form of cylindrical quadrants are plainly shown at the bottom as is also the scale car beneath them. A locomotive crane standing on an adjacent trestle, and in a position to discharge ore into the railroad car standing on the bin trestle, is also clearly shown.

The construction of the bins is well shown by the photograph Fig. 17.

Fig. 18 shows the bottom of the bins with their chutes, also the scale car and its operator. It will be seen that the quadrant gates are operated by a pair of connecting rods attached to crank pins, carried on a heavy gear shaft, supported at the top of the chute. The large gear is driven by a pinion which in turn is driven by a pair of bevel gears. From the vertical shaft of the driver of these depends

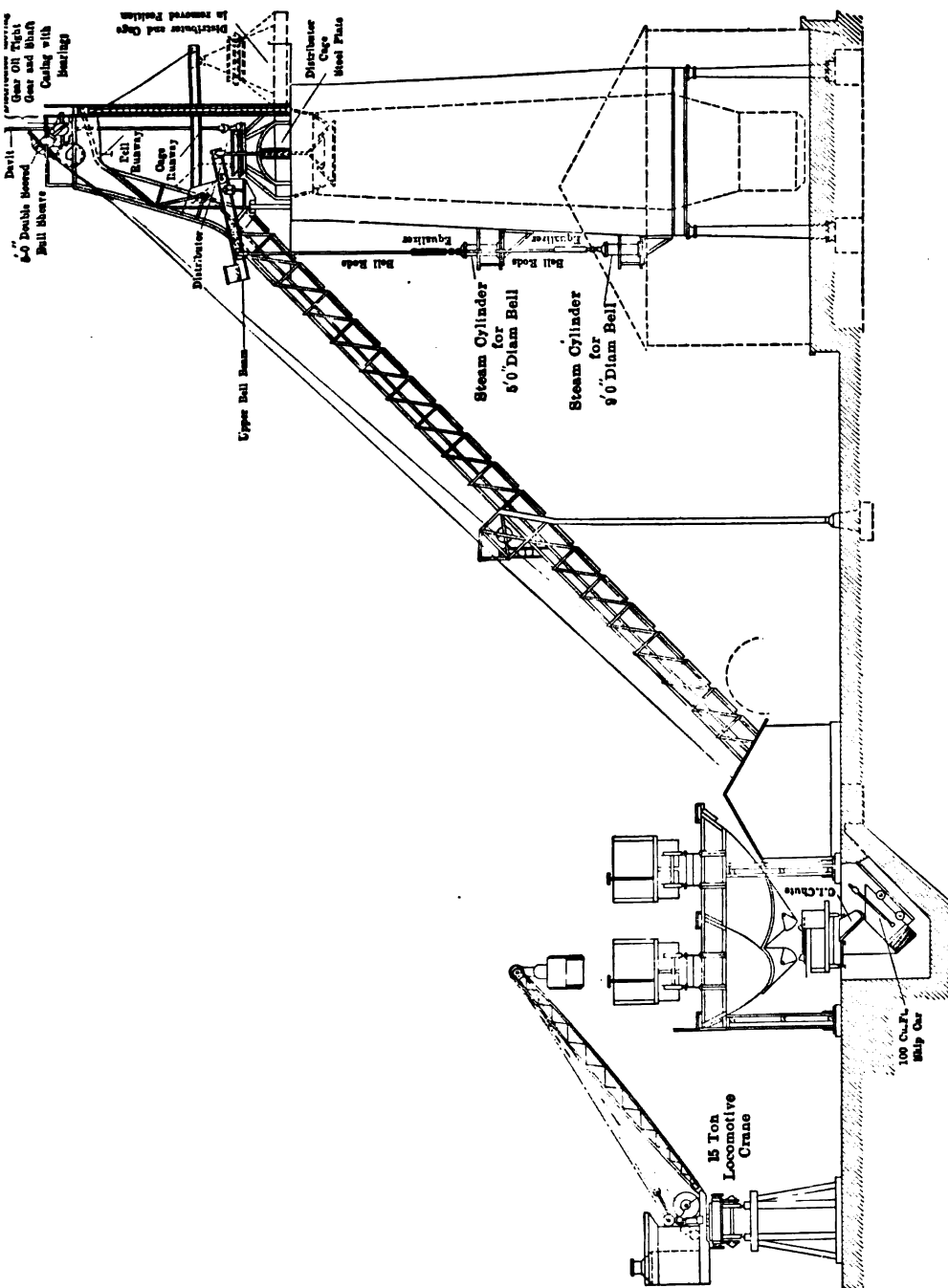


Fig. 16. Furnace with Brown skip hoist and parabolic bins.

a shaft carried by a universal joint and carrying a socket at its lower end. The scale car carries a square-headed shaft, which can be thrown up by the operator to engage with the socket for any chute. After this is done a small motor is started and the gears are revolved until the crank pins come to the bottom, in which position the gate is wide open. When the required amount of stock has been drawn the gate is raised by revolving the large gear shaft through another half revolution.

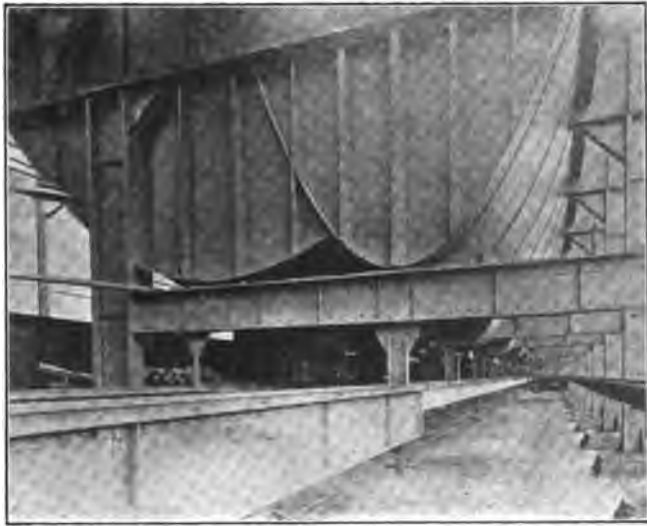


Fig. 17. Parabolic bins.

The style of bin and chute designed by Hoover & Mason is shown in Fig. 19. No attempt is made in this bin to use the parabolic shape, which is open to the objection that its angle changes, so that while it may be steeper than necessary in some portions it is flatter than necessary in others, and the latter condition prevails near the bottom, where the flow should take place most freely.

The bottom of the bin is formed by a horizontal roller five feet in diameter which lies close to the bottom edge of the chute, so that no material can get between the two. This can be rotated at the will of the operator in the direction shown by the arrow. The angle from the top of the chute opening in the bin to the top of the roller is considerably less than the angle of repose of the material, so that no material can possibly get out of the bin when the roller is stationary. On the other hand, when it is rotated the material is carried forward by the roller to a point at which its slope is greater than the angle of repose of the material, which then slides off. When the roller is stopped the flow of material instantly ceases.

The front of the bin is built with louvres with a reverse slope, through which it is impossible for the material to make its way out, but through which it is very easy for the operator to thrust in a bar and break any bridge or arch that may form to obstruct the flow.

The roller is driven by means of gearing thrown in by a clutch worked by the operator. The gearing is actuated by a line shaft or driving shaft, which runs continuously. There is a separate roller for each discharge, the equivalent of each chute in the older type of con-

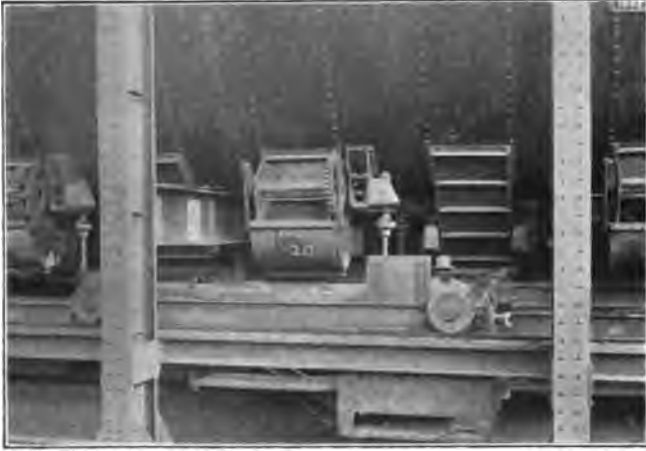


Fig. 18. Bottom of Brown hoist bins with their chutes, and scale car with operator.

struction, and the design is such that the ends of these rollers come very close together, leaving a minimum of space between them, so that the bin is practically open at the bottom all the way along. This to a great extent prevents the formation of accumulations of ore, as these have no foothold on which to begin to form, the bottom of the bin being kept clean by the continuous sliding of the material over it, and no bridges between chutes existing. For the coke bin the roller is perforated, and by an ingenious arrangement made to serve as a screen for the removal of the fine material from the coke. This action is always complete and automatic because the roller cannot run as a feed device without also acting as a screen.

The transfer car used in bringing the ore from the bridge to the bin is shown in dotted lines above, as is also the overhanging end of the ore bridge with its grab bucket and trolley.

A gate has been introduced by the Wellman-Seaver-Morgan Company, which is on the same principle in all particulars as that of Hoover & Mason except that the former uses instead of a roller, an endless belt made of overlapping metal slats mounted on sprocket

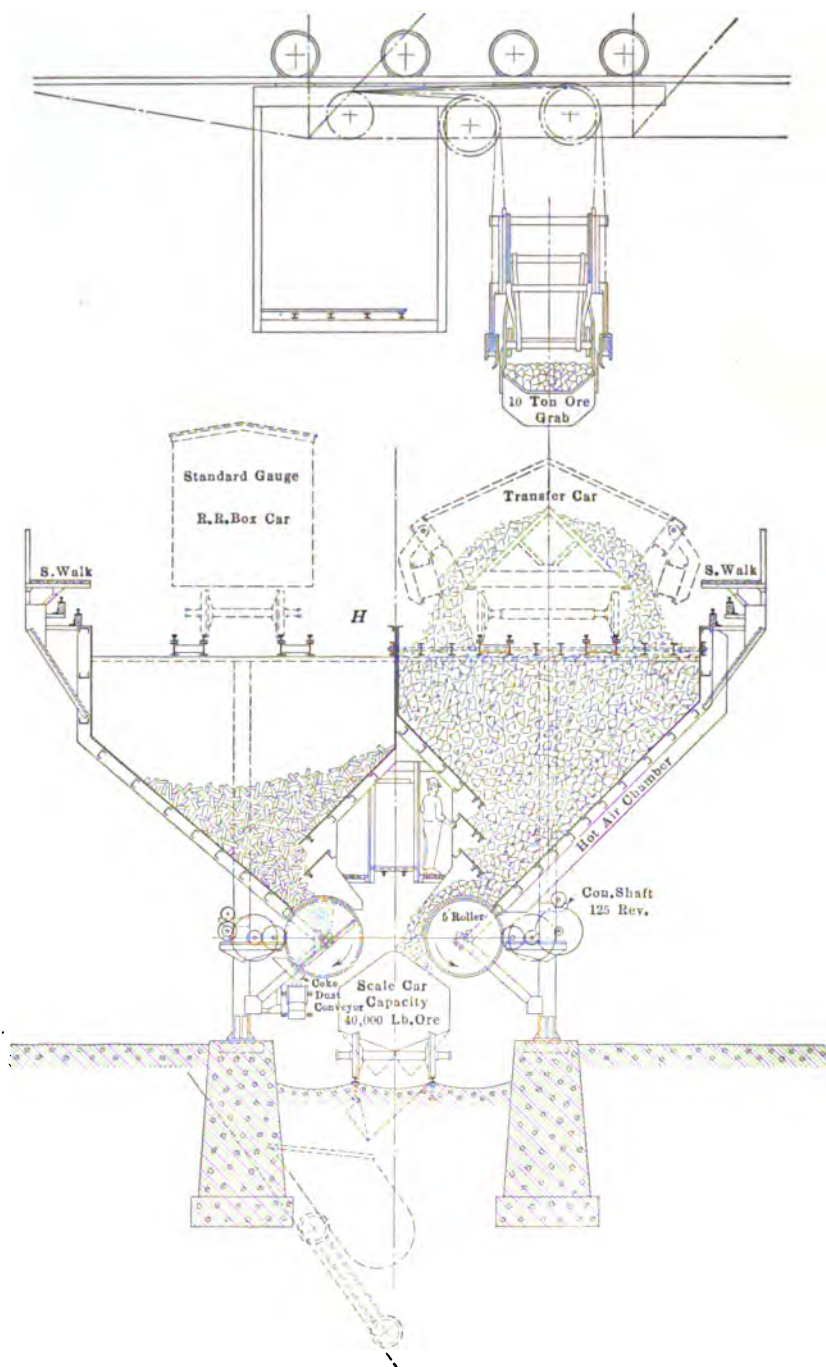


Fig. 19. Hoover and Mason bin and gate.

chains, as shown in Fig. 20. The pressure of the stock on top of this is taken by beams lying inside the endless belt, on which its upper half slides. Owing to the location of this apparatus up underneath the bottom of the bin, the construction is not as clearly shown by the photograph as might be desired, but the overlapping metal slats and



Fig. 20. Wellman-Seaver-Morgan Gate. — Endless belt made of overlapping metal slats on sprocket chains.

the sprocket chains are visible, and the operation will be understood from the description of the Hoover & Mason apparatus. The metal belt acts as a bottom to the bin and carries the material bodily forward until it drops over the driving-sprocket end into the scale car.

It will be noted that all three of these designs which jointly have probably been applied to a greater tonnage of bin capacity than all other types combined used power for the operation of the gates.

This is because of the difficulty that has often been met in operating hand gates quickly and positively, to which I have already alluded. At the same time it must be understood that many hundreds of bins are in successful use with hand-operated gates, which have the advan-

tage of greater simplicity and lower first cost than any of the power-driven gates.

Fig. 21 shows an outline drawing of the Baker suspension type of bin built by Arthur G. McKee, Contracting Engineer, Cleveland, Ohio.

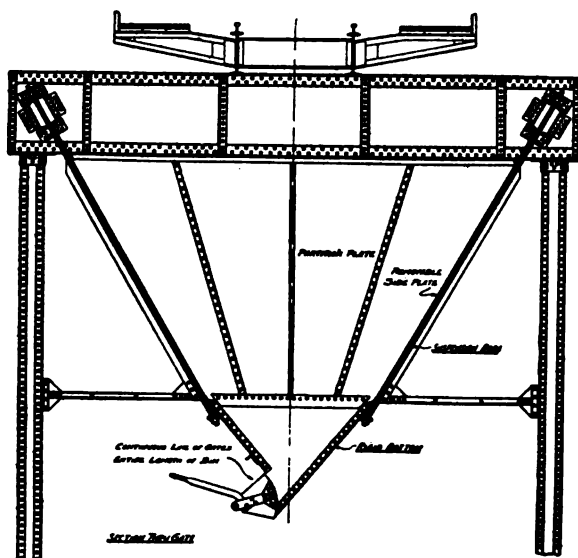


Fig. 21. "Baker" suspension bin with hand-operated quadrant gates.

The gate in this type of bin is a quadrant of a cylinder, but in the reverse position to that used on the Brown bin. The axis of the cylinder is so located that the flow of the material tends to close the gate, so that it is not liable to be opened accidentally. The gate is operated by the scale-car operator through the lever shown in the drawing.

Owing to the absence of machinery these gates are only

separated from one another by the small space necessary for clearance, so that the opening in the bottom of the bin is continuous and the formation of bridges and building up of the ore inside the bins is thereby prevented to a great extent.

These bins are, like the Brown, of the suspension type, but instead of their cross section being that of the true parabola it is made up of four tangents thereto, which give to a large extent the same freedom from distortion that comes from the use of a true parabola, any minor stresses of this nature being taken up by the transverse partition plates and the rigid bottom.

A considerable tonnage of these bins is in successful operation at various plants and there are many others with other types of hand-operated gates, some of which are entirely successful.

Methods of hoisting in mechanical charging.—In hoisting for mechanical filling, as apart from distribution (the latter being used in the technical sense of distributing the stock properly in the top of the furnace), there are two main systems in use to-day, and a third which is a combination of some of the features of each.

In the first system the stock is drawn from the bins into large

round buckets, whose bottoms consist of a cone, or "bell," which is merely a large conical valve attached to a rod running up through the center to a hook at the top. This bucket is then transported to the bottom of the hoist and sent up, hanging by the hook at its top, to the top of the furnace, on which it is seated and then dumped by lowering the hook on the central rod carrying the bell. In this system the material does not break bulk from the bin to the furnace top.

Different systems of rotating the buckets are in use, but this subject can more appropriately be discussed under the head of stock distribution. Various methods have also been used for lowering the bucket on to the furnace top after it reached the proper position. But while these differ from the one illustrated, they do not differ sufficiently in principle to make detailed description necessary.

In the other system a sort of tank, either rectangular, round or elliptical, which is called a skip, runs on an inclined plane, generally very steep, under the control of the hoisting rope and supported by wheels running on a track on the incline. This runs from a pit beneath the filling floor to a hopper above the furnace top, where it turns upside down and dumps, then returns to the bottom, its travel being thus confined entirely to the inclined track running to the furnace top, and known as the skipway.

This skip is usually filled from a motor-driven dumping car, with its body or dumping hopper mounted on a scale carried by the truck, called the scale car or larry. This car is traversed along in front of the bins and filled from them. It is then returned to a hopper or chute, which delivers into the skip when the latter is in its bottom position, and there dumped, returning for another load while the skip is hoisted to the furnace top.

In this system it will be seen the stock breaks bulk between the bins and the top of the furnace.

At some plants a combination of these systems is in use, in which the bucket with the bell bottom is never removed from the suspension truck on which it is carried, or only to a turntable serving it, and plies therefore only on the incline, being filled by a scale car exactly the same as a skip. The bucket in this case virtually becomes a skip which dumps through the bottom while retaining its upright position, instead of being turned upside down, as is done with the regular skip.

The first type of distribution is shown in Fig. 23, which shows the Ford-Parks modification of the original Neeland top.

The second of these styles of hoisting is well shown by Fig. 16, which is the design of Alexander E. Brown, and with which in connection with the distribution at the top of the furnace we shall deal more at length later.

Many variations of each of these systems are in use. Very frequently in the case of the skip hoist the coke bins are arranged on each side of the skipway, and coke is spouted directly into skips without the intervention of the scale car, the quantity of coke being measured by skipfuls instead of by weight. This is a very satisfactory system if the same coke is always used, but one liable to produce great derangement of the furnace if sudden changes are made from one coke to another of very different density.



Fig. 22. McKee-Baker suspended bin with continuous line of gates, hand operated.

The skip hoist is built with both single and double skips. The advantage of the double skip is that it is perfectly counterweighted, without extra mechanism for that purpose, and that it has a very great capacity. It, however, labors under the disadvantage that it discharges the stock at two points, one each side of the central plane, rather than at one point exactly in the central plane, as is done with the single skip.

The skips dump on opposite sides of the main central plane and on the same side of the central plane at right angles to it, this causes a lack of symmetry, and the irregularities of the distribution due to this, if not compensated, or eliminated by suitable means, are

likely to cause very serious derangement of the working of the furnace. The elimination of these irregularities is made much easier if the skip dumps exactly in the central plane.

A double skip was put in use at the Pueblo plant of the Colorado Fuel and Iron Company a number of years ago, designed by Mr. E. G. Rust, in which the advantages of both the single and double skips were obtained by a most ingenious design. Both skips run in the central plane and occupy the same positions at top and bottom. Of course when one is at the top the other is at the bottom, and there is no fouling in those positions, but in order that they may pass each other the tracks starting from the top and bottom diverge from one another in the vertical plane so that they are separated vertically at the middle of the skip bridge by a sufficient distance to allow the under skip to pass beneath the upper. The gauge of the track for the upper skip is wider than that for the lower, which runs between the rails of the upper track. The deepening of the skip bridge at this point tends to give it additional strength at the place it is most needed.

This system has been in use at the Pueblo plant for a number of years, but for some unknown reason its use has never extended widely.

Location of the hoisting sheaves. — One of the difficulties met in skip hoist design is that commonly the hoisting rope must run over a sheave located at the upper end of the skipway and come back over the top of the skip in order to be out of the way of the stock when the skip dumps. This brings the rope above the skipway while the hoisting engine is generally most conveniently located underneath the skipway.

Various arrangements have been used to overcome this difficulty. In one design a truck is used which carries the skip at its upper end and practically pushes it up the incline, the skip being pivoted to the truck and having an auxiliary pair of wheels in the front. In this case the sheave is put below the skipway and is far enough below the skip when it dumps to be out of the way. This puts the rope under the skipway where it is most desirable to have it.

In a number of cases the ropes have been carried clear over the top of the furnace, and the hoisting engine placed on the opposite side in order to overcome this difficulty, while in one well known type of top two guide sheaves are used on each skip rope, in addition to the main hoisting sheave, in order to get the rope out of the way at the top and pass it back underneath the skipway.

In the Brown design of skip hoist the difficulty is solved by the use of the single skip, and by putting the hoisting sheave in a plane parallel with the skipway as shown in Fig. 16 so that the hoisting rope can be returned over one side of the skipway to the engine house beneath it.

Probably other solutions of this apparently trivial problem have been attempted or made, but these are the ones best known and most used.

Dumping the skip. — The method for turning the skip over to dump is universally the same. The main rails of the skipway bend down from the incline and run in level when they reach the top of the hopper, but there are two additional rails set to a somewhat wider gauge which continue on in the main line of the skipway. These are set far enough apart so that the front wheels can pass through them without touching, all the wheels being outside the skip. The rear wheels have a supplementary tread outside the regular one, which comes onto these supplementary rails just where the main rails bend down from their straight line. This carries the rear wheels on up while the front ones go forward on a level line, and in something less than twice the length of the skip it is turned up to an angle of forty-five degrees or more and so emptied completely.

Counterweighting. — The bucket type of filling must use a counter-weight in order to avoid excessive consumption of power, and more difficult control in handling its loads, because from the nature of the case the bucket type of filling must be of the single-hoist variety and therefore unbalanced.

Various methods of arranging the counter-weight are in use. Very generally a vertical tower is used of somewhat less height than the furnace, in which a weight is raised by the counter-weight rope, when the skip is going down. A system of sheaves is used like an ordinary block and tackle in order to get the required counterweighting effect with a short travel by using a proportionately heavier counterweight, as shown by Fig. 23.

The Brown hoist when designed for a single skip eliminates the problems of reversing the engine and of counterweighting the skip by using a hoisting engine in which the drum is connected to the engine shaft through a friction clutch under the control of the operator instead of the ordinary hoisting engine in which the drum is keyed to its shaft and positively connected to the engine shaft through gears. The engine runs always in one direction and the skip is hoisted by throwing in the clutch. On the return trip the skip is allowed to run back by throwing out the clutch and controlling the drum with a brake.

The better type of engine which can be applied by eliminating the need for reversing makes this system more economical, in spite of its loss of power in hoisting the unbalanced skip, than is the ordinary system with the skips balanced but using the very uneconomical type of reversing engine previously described. The Brown system, however, is open to the objection that it requires some skill on the part

of the operator in throwing in and out the clutch and lowering the skip with the drum brake, whereas the counterweighted system can be made entirely automatic as to control, etc., by the use of the slow starting and slow stopping devices previously described.

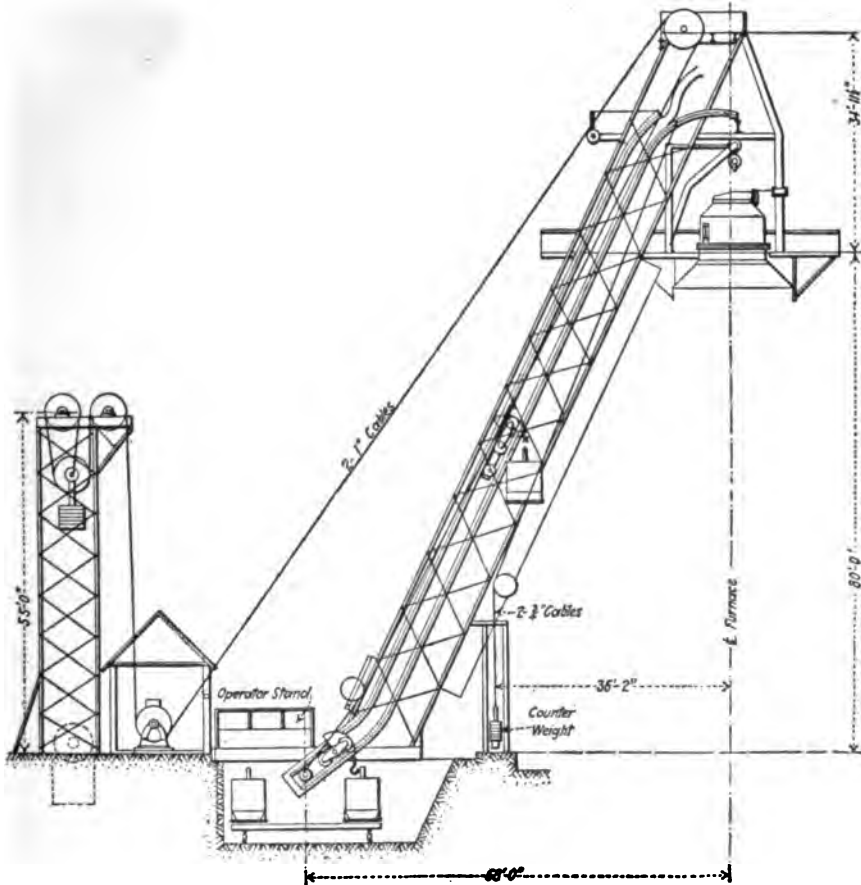


Fig. 23. Ford-Parks system of bucket filling.

Larry cars. — These are almost always used with skip filling and sometimes also with bucket filling. Their essentials are in general always the same, but the details of their arrangement vary greatly. These essentials are a truck, motive power for the truck; a hopper with means for quick and complete discharge, and scales on the truck supporting the hopper. Frequently also there are means for operating the gates on the bins.

Several of the preceding illustrations of bins have shown scale cars also and from these a good idea of the standard types may be

obtained. They may be either of the suspended type with their rails elevated close up under the bottom of the bins, which has the advantage that nothing can fall from the chute or hopper onto the rails; or the rails may rest on ties on the ground as in standard railway track.

Many systems of discharge gates have been used and in general the details of the design of these cars are adapted to the conditions of the individual case and the judgment of its designer.

A modified type of larry is used with the original bucket type of filling in which the buckets are removed from the hook of the hoisting truck and taken directly to the bins to be filled, but in this case the more appropriate name of scale car is used.

These differ from the larry principally in having a platform in which the bucket rests instead of a hopper; while, like the larry, their detailed design is adapted to the conditions of the given case.

Scales. — One of the most important details of the whole system of charging a furnace, which as a whole is probably the most important single part of blast-furnace operation, is the weighing of the materials. It is customary to look upon the blast-furnace as a rough, not to say crude, apparatus. This view is justified in part by the enormous forces which it must handle and keep under control. But as a matter of fact in spite of its size it is one of the most sensitive pieces of apparatus in industrial use and runs on smaller margin of safety in fuel than any other of our great industrial operations. Changes of the "burden" (a technical name for the weight of ore for a given fuel charge) as small as one per cent are not infrequently used in adjusting the operation of the furnace to make the kind of iron desired with a minimum consumption of fuel. Changes of two or three per cent are as large as are often made to adjust for the ordinary variations of operation. Such adjustments necessitate accurate weighing, and the lack of this has often been accountable for bad furnace operation, and even more often, for cases in which claims of remarkable furnace work were based upon inadequate or incorrect knowledge of the weights of the different materials actually used. Not infrequently the consequence has been a bitter disappointment when the book inventory of the material on hand was compared with the actual stock of such material.

Cases are on record too numerous to mention in which the books have shown the presence in the stock house of thousands of tons of material, and the financial returns have been estimated on this basis only to find on investigation that the material, so plainly shown by the books, had been put through the furnace and was conspicuous by its absence from the stock house. This has sometimes happened with the knowledge, or even through the deliberate action of a dis-

honest superintendent, but has also often happened to an honest one who had too great confidence in his scale weights. This condition is now so well understood that the financial management generally insists on a monthly or weekly inventory of the actual material on hand, and its comparison and reconciliation with the figures taken from the furnace books.

The scales used for charging purposes have to meet certain special conditions, and therefore were early designed by the scale makers for this purpose, and given the name of "charging scales."



Fig. 24. Furnace charging scale.

The type of these in common use with the barrow system of filling is shown by Fig. 24 (Fairbanks & Co.). These are platform scales with the base sunk in the floor of the stock house so as to bring the platform level with the floor. In recent years these have nearly always been of the suspended type, the platform being carried by four suspension rods from the scale-levers over head. This takes the latter up out of the way and out of the dirt in which they were necessarily more or less buried with the older type of scales, in which the levers were in a pit below the platform.

A special condition that these scales have to meet is that as a general thing at least three and generally more kinds of material have to be weighed — fuel, ore, and flux (limestone or dolomite), and a definite amount of each is required for each charge.

In order to meet these conditions the scales are built with from three to six separate beams, any one of which can be lifted up out of operation or lowered onto a frame depending from the main beam, so that the two operate as one. The main beam is usually used to balance the weight of the empty barrows, and one of the secondary beams is then thrown in for each material to be filled, its pea being locked fast for the charge weight wanted, this particular beam then rises and falls according to the weight of the given charge in the barrow. When this has been adjusted by adding or subtracting material this beam is thrown out and that for the next material thrown in.

The introduction of mechanical filling brought about the necessity for a different arrangement of the scales, and the trucks which carry the buckets to the bins in the bucket system of filling are provided with scales under the platform on which the bucket rests; or in the case of the larry car used with the skip, the hopper is carried directly by the scales which constitute a part of the truck. The same system of beams has in some cases been used as in the stationary charging scales, but in more recent years it has been found extremely desirable to use a recording type of scale.

The first of these ever installed, so far as known to me, was built by the Streeter-Amet Company of Chicago, for the order of Mr. W. L. Kluttz, then superintendent of the Thomas plant of the Republic Iron and Steel Company.

This scale carries a large circular dial, around which a pointer travels as the weight on the scale increases. Certain fixed markers are attached to the face of the scale, in positions corresponding to the burden of the different materials wanted, and the scale-car operator can watch the gradual rising of this pointer toward the desired weight, so securing much more accurate weights than is possible when the only indication given by the scale occurs during the brief instant while it is in balance, since then it is generally overloaded before the supply of material running in can be cut off.

These scales are also provided with a paper tape, and by means of a lever, which is pulled when the correct point is reached for each portion of the charge, the actual weight on the scales is stamped on this tape, which is locked up in the scale box, entirely inaccessible to the operator. At any interval desired, generally once a day, this tape may be taken out and examined to see the accuracy of the weights actually obtained, as compared with those called for by the pointers.

The moral effect of this on the scale-car operator is tremendous, and vastly better results can be secured by the use of such an apparatus.

The writer became general superintendent of the plant mentioned between the time that this experimental apparatus was ordered and the time it was put in operation. The change produced in the accuracy of the weights obtained was almost beyond belief and the work of the furnace on which the scale was used immediately improved very much.

Since that time the American Kron Scale Company has brought out a similar device by which the same results may be obtained. The practical importance of this matter is so great, and the moral effect upon the scale-car operator caused by the knowledge that a continuous record is being made of the way in which he is doing his work, is so important that it is doubtful if any furnace is justified in doing without such equipment.

The scales on scale cars are subjected to a very severe service. They not only have to receive the impact and shock of the incoming material, but they have to stand the much more serious shocks arising from irregularities in the track on which the scale car runs. The great inertia of the charge on a loaded scale car causes enormous stresses on the knife edges even with apparently insignificant irregularities in the track. For this reason switches, cross-overs, and other breaks and irregularities in scale-car tracks should be avoided to the greatest possible extent. Moreover, these cars should always be provided with springs over the axle boxes, or in other suitable location. These springs should be the softest, that is, have the maximum travel for a given change in stress, permitted by the conditions, as in this way the springs absorb the shocks arising from the irregularities of the track and keep them off the knife edges.

I have seen scale cars built entirely without springs, and at the same time heard the furnace managers complain bitterly that it was impossible to get his scales to stand up and give accurate service, without his realizing the reason.

Means have been provided whereby the weight of the charge hopper was lifted off the knife edges except during the time that it was actually being weighed. But it is ordinarily difficult to get scale-car operators to use this device. There seems no reason why it should not be made to interlock with the traversing motor of the car, so that the latter could not be moved except after relieving the knife edges of the scales from weight.

This may seem a matter of too little moment to deserve such serious mention, but when the importance of accurate weighing previously mentioned is considered, and when it is realized how utterly unreliable the best scales become when their knife edges are even slightly worn, it is believed that the stress laid on this subject will be justified.

CHAPTER II

FILLING THE BLAST-FURNACE

THIS is the most important single step in the whole iron-making process. The details by which it was carried on in early years are quite unknown to me. The earliest system of which I have knowledge consisted in throwing into the open furnace top the ore and limestone from large wheelbarrows, while the charcoal was thrown in from baskets made for that purpose, these baskets being elliptical in shape, about 4 ft. long by $2\frac{1}{2}$ ft. wide by 1 ft. deep, with hand-holds at each

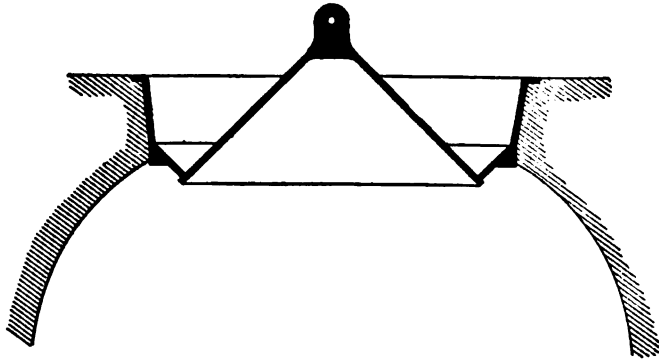


Fig. 25. Single bell and hopper.

end. When mineral fuel was used it was handled in wheelbarrows, and even before the introduction of the closed top the use of "filling-barrows" became almost universal except at charcoal furnaces. These barrows are the two-wheeled type illustrated in the last chapter.

The first method adopted for closing the top of the blast-furnace was the one which has remained in use practically ever since. The apparatus is known as the "bell and hopper." In its simplest form it is illustrated by Fig. 25. It consists of an inverted cone forming a hopper set on, or in modern practice, fastened to the top of the furnace, the opening of the hopper being closed by a cone which sometimes has a rounded top and from its general shape takes its name, the "bell." The bottom edge of the hopper is turned true in a boring mill as is the lower portion of the surface of the bell, so that they make a good fit. Into the annular space of triangular section formed by these two, the charge is dumped, by tipping forward the barrows on their

own axes as a center, then when the bell is lowered, the charge slides into the furnace through the annular opening formed.

During the long period in which the furnace was approximating its modern development, ending with the Duquesne revolution, this method of filling was almost universal.

The quantity of labor it involved was well recognized, and many efforts had been made to avoid this by the introduction of mechanical methods of charging; but these have almost universally had a highly detrimental effect on the operation of the furnace, so that in earlier times they were soon abandoned for the time-tried method universally known as "hand-filling."

It seems at first sight absurd that so simple a matter should be so obscure and should involve such great difficulties. But the spacing of the stock on the bell, the dumping of the barrows at the edge of the hopper, or on the apex of the bell, the size of the charge, and whether the ore and stone should be dumped with the coke, or separately, are all questions which may exercise an influence on the working and economy of the furnace so great as to be literally vital.

The laws of stock distribution. — This is a field in which we have little or no theory to guide us. Our information comes solely from tedious and expensive empirical methods, better described as "trial and error." Our knowledge of what constitutes correct filling comes solely from our observation as to how furnaces work with different types of distribution, and while the whole history of this vast subject abounds in contradictory experiences, such as the failure of apparatus and methods of operation at one plant which have made a brilliant success at another, and other facts difficult or impossible to reconcile with one another, certain laws stand out as established by experience so nearly universal that I believe no one will question them.

These laws are:

First — The distribution of each kind of stock in the furnace must be symmetrical, about not less than two axes making equal angles with each other.

Second — The same proportion of lump and fine must obtain in each of the segments into which the circle of the top is cut by these equally spaced axes.

Third — The distribution of fine and coarse material radially must be such as to produce as nearly as possible an equal ascent of gas through each portion of the furnace stack.

To these must be added in some cases, if not in all, a fourth — The stock should be distributed not in uniform annular rings around the hopper, but in heaps, equally spaced around it.

In further explanation of the first law it may be said, on the authority of many trials, that it is not sufficient to dump all the stock sym-

metrically on one diameter of the furnace. No matter how carefully it may be spaced along that diameter, or even if it be dumped by tipping to first one side and then the other of the diameter, the results are unsatisfactory. This is for the reason that the tendency of this method of filling is to make two or perhaps three flat columns of coarse material separated by one or two flat columns of fines as indicated

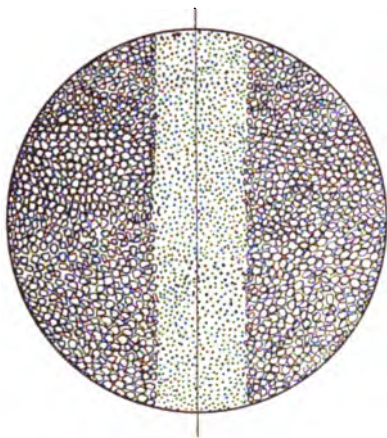


Fig. 26. Sketch of distribution when charging along one diameter, one wall of fires.

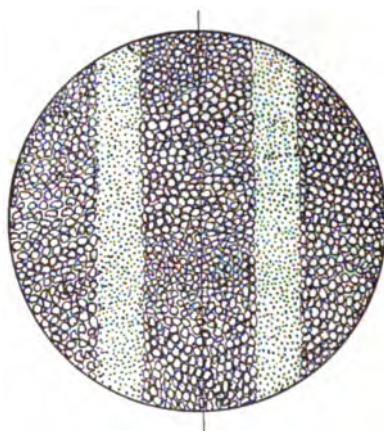


Fig. 27. Sketch of distribution when charging along one diameter, two walls of fires.

in Figs. 26 and 27, and the gas travels so much more freely through the coarse material that this descends much more rapidly than the fine, and reaches the hearth in an unreduced condition, or perhaps the opposite action takes place, and the gas being unable to penetrate the columns of fine material, does not reduce it adequately, so that it reaches the hearth improperly reduced. At all events one portion of the stock is reduced ahead of the other and the quantity of fuel which must be burned in the hearth is that required by the least reduced portion, which therefore limits the economy of the furnace. We must, therefore, dump the stock on two axes at right angles, three at 60 deg. apart, or four at 45 deg. We can use some angle not commensurable with 360 deg., but the angle in that case also must be constant; this produces the spiral effect described later.

When hand-filling is used it is quite easy to secure compliance with all four of the laws above stated. By dumping at four or six symmetrically placed points around the hopper, with barrows of the same sort of material, we comply with the first two laws. By the proper adjustment of the size of the bell to the diameter of the stock-line we comply with the third, and the essence of the system involves com-

pliance with the fourth, that is, dumping in heaps symmetrically placed around the bell.

Hand-filling requires that top-fillers be carefully trained to their work, and that some pains be taken to see that they do not dump all the material on the side next to the hoist or incorrectly in other respects. This is a grave temptation to them when the furnace is driving rapidly, and they are pushed to keep up. Their succumbing to this temptation has been the ruination of more than one furnace manager who could not catch them at this trick, or stop them from it; because nothing will more quickly and completely ruin the successful operation of the furnace than filling on one side or in any other irregular way.

Even though the top fillers are well trained and faithful, there remain certain precautions to be taken even with this simple and easy system of filling. The necessity for these arises from two causes. First, the distribution and shape of the four heaps on the bell, if they are dumped consecutively, are not all alike by any means. Second, the charges are practically never made up of a number of burrows of each material divisible by the number of dumping points. That is to say, we may easily have four or six barrows of coke to the charge, to agree with the number of dumping points, but this having been determined, we must have a number of barrows of different kinds of ore and of limestone, depending upon the weight of the coke charge so established, and these numbers will not commonly, in fact seldom or never, be similarly divisible by four or six as the case may be.

The lack of symmetry of the different heaps in the hopper when dumped consecutively is due to the fact that the first barrow dumped, striking the hopper when it is perfectly empty, spreads out laterally in both directions. The second one dumped on the diameter at right angles to it, endeavors to do the same, but the pile which it tends to make is stopped from spreading toward the first barrow dumped by the pile formed by the contents of the latter. Consequently the contents of the second barrow spread freely on one side, but much less freely on the other. Thus the center of gravity of its contents does not lie in its dumping plane, but is deflected away from the first dumping point. The action in the case of the third barrow dumped is exactly the same, it in turn is forced around by the pre-existing heap from the second barrow. When we come to the fourth barrow, the space into which it would naturally spread out laterally, is cut off on one side by the heap from the first barrow, and on the other side by the heap from the third, with the result that this heap is very generally higher and always much narrower than that from any of the other barrows.

Instead of having a circle divided into four equal parts of 90 deg. each, we have the first of 100 deg., the second of 90 deg., the third

of 90 deg., and the fourth of 80 deg., or some similar arrangement. This, of course, lacks much of the ideal symmetry which is required not only by theory, but rigorously demanded by the results of practice.

To overcome this lack of symmetry and also that due to the fact that the total number of barrows in a charge is frequently not divisible by the number of dumping points around the hopper, we have a simple means not as universally used as it should be. This consists in shifting the first point of dumping on the bell one space each time. A very easy method of accomplishing this result is to have a number of barrows, one more or one less than an even multiple of the number of barrows in the charge. Then if pains be taken to see that the fillers go round the top always in the same direction, the first barrow dumped on each charge will always be one space away from where it was the last charge. On the next, another space, and so on until within a comparatively few charges the circuit has been made, and the first barrow comes back to its starting point. This means that while each individual charge lacks much of symmetry, its initial point is revolved so that each portion of the furnace in turn receives the same treatment, thus producing what is known as "spiral filling," since any given point, such as the dumping point of the first barrow, in the successive charges as they descend through the furnace, makes a series of steps very similar to those of a "spiral" (helical) staircase.

How old this method of filling may be I do not know; it was first called to public attention in a paper before the American Institute of Mining Engineers by W. A. Barrows, then at Sharpsville, Pennsylvania, about ten years ago. On account of the important irregularities in any one charge whose origin I have tried briefly to describe, this or some similar system, giving analogous results, should always be used in hand-filling.

When two top-fillers are employed another system can be employed with good results. This consists in having the two men dump their barrows at points immediately opposite one another, and at the same instant. The next time they dump opposite to each other again, but in the case of 4-point dumping this, of course, means, at right angles to the first position. The two pairs of heaps so produced are not similar but each one is similar to its opposite, and by alternating the position for the first dump the series of charges formed are all symmetrical about two axes, although the heaps on one axis are not like those on another, but these are alternated so that in the course of a double charge we even up the inequalities of one charge with those of the next. It is more difficult to secure this sort of filling than it is spiral filling, and this kind should not be used in preference to the latter except under unusual circumstances.

The size of the charge unit to be used, and whether the coke and

ore are to be dumped all at once or separately are questions of operation rather than of construction, and will therefore not be discussed here. But in a general way we may say that coke charges range from six thousand pounds for small furnaces, up to fifteen thousand, and even eighteen thousand pounds on larger ones, while the best practice

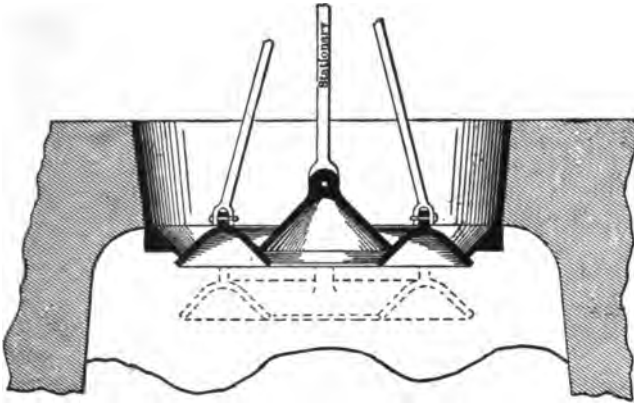


Fig. 28. The Bauman bell and hopper.

undoubtedly favors dumping the coke separately from the ore and stone. Similarly the question of the diameter of the bell which controls the radial distribution of the stock is a question of operation, and not one of construction, since the same construction is used in both cases, with only a relative slight difference in dimensions, and this question can therefore be passed over here.

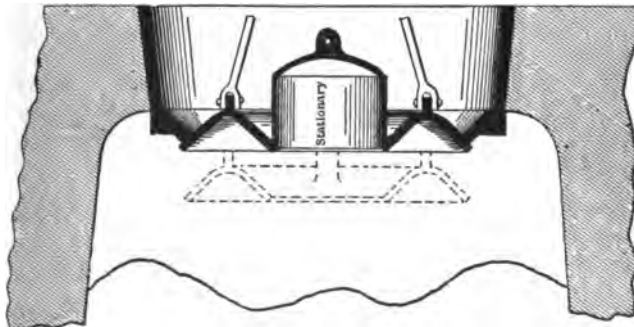


Fig. 29. Firmstone's modification of the Bauman bell and hopper.

Variations of the bell and hopper used with hand-filling.— Many modifications of the bell have been made with the object of securing better distribution and better furnace work. These have sometimes been only changes in dimensions, but many other variations have been used as well. A number of these are shown in Figs. 25, 28, 29, 30, 31,

32, 33, taken from a paper by the late T. F. Witherbee before the American Institute of Mining Engineers, Vol. XXXV, entitled "Special Forms of Blast-Furnace Charging Apparatus."

Fig. 31 is representative of a number of these, this being the Firmstone modification of the Bauman or double bell. The center of the cone forming the ordinary bell is cut away by an inverted cone having the same angle of slope as the bell, normally 45 deg., and the opening

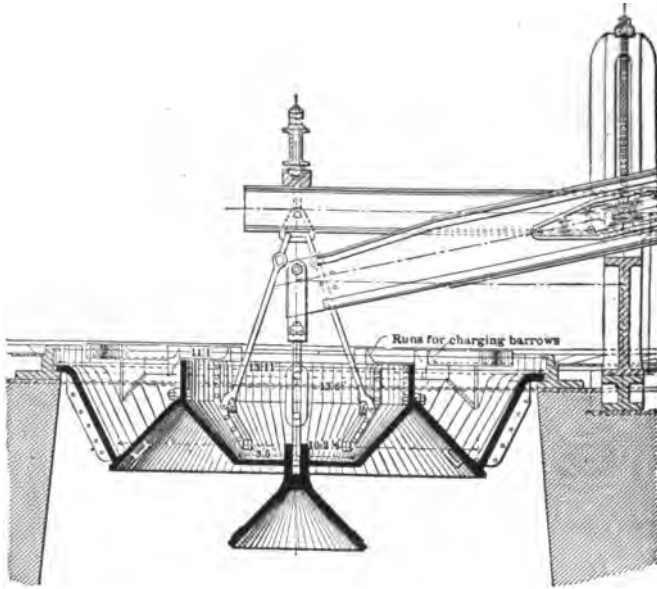


Fig. 30. The Durham bell and hopper.

so formed is closed by a (nearly) stationary part commonly called, by those who use this type of top, the "plug." This is not quite stationary for the reason that the inner and outer surfaces of the bell must both make a good joint. It would be impossible to maintain an adjustment of the parts which would secure this if both seats were rigid, so the plug is counterweighted until its effective weight is very small and allowed a drop of about a half or three quarters of an inch, which permits it to follow the bell down for this distance on the opening movement, while on the closing movement the bell picks it up and makes the joint on its inner seat first, then reaches its seat on the outer surface or hopper afterwards, carrying with it the plug through the distance the latter dropped in opening.

Fig. 31 differs from the other types shown in that the gas outlet takes place through its center, there being no flues in the side walls of the furnace. This secures an absolutely symmetrical distribution of

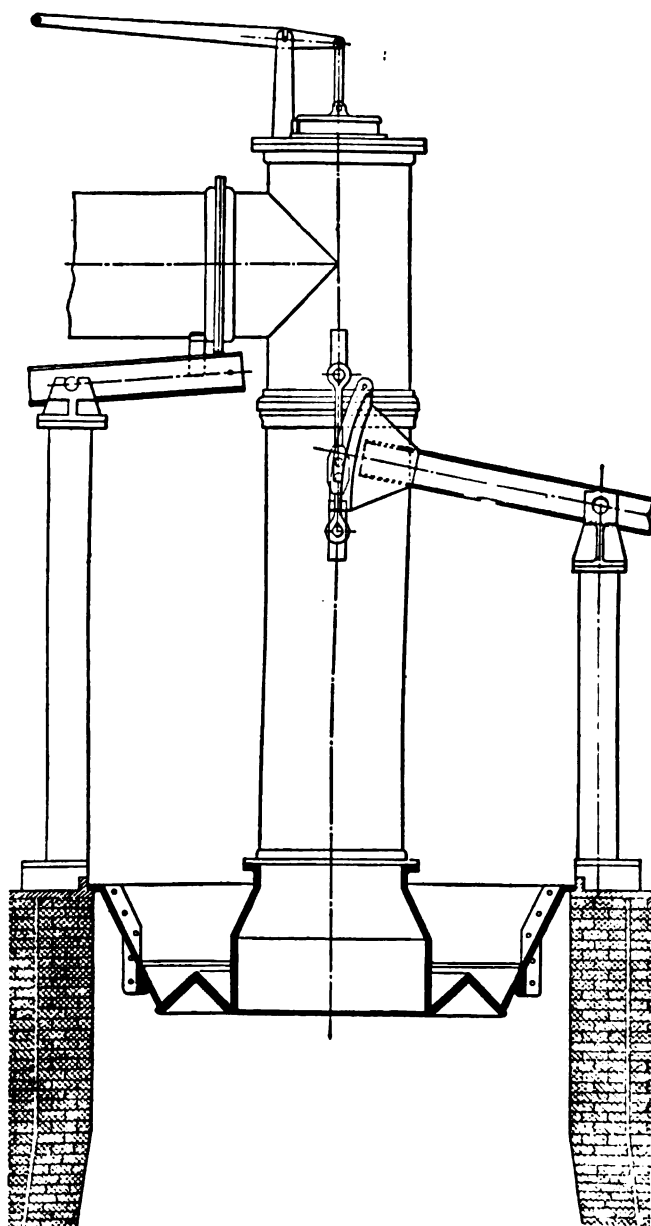


Fig. 31. The Bauman-Firmstone bell and hopper at the Longdale furnaces.

the gas as well as of the stock, and while the former is less important than the latter, it is still very important.

Tight joints in the pipe are maintained in spite of the rise and fall of the center plug by ball joints at each end of the horizontal pipe, shown broken off at the left-hand side of Fig. 31. The ball joint not shown is at the top of the down-corner over the side of the furnace,

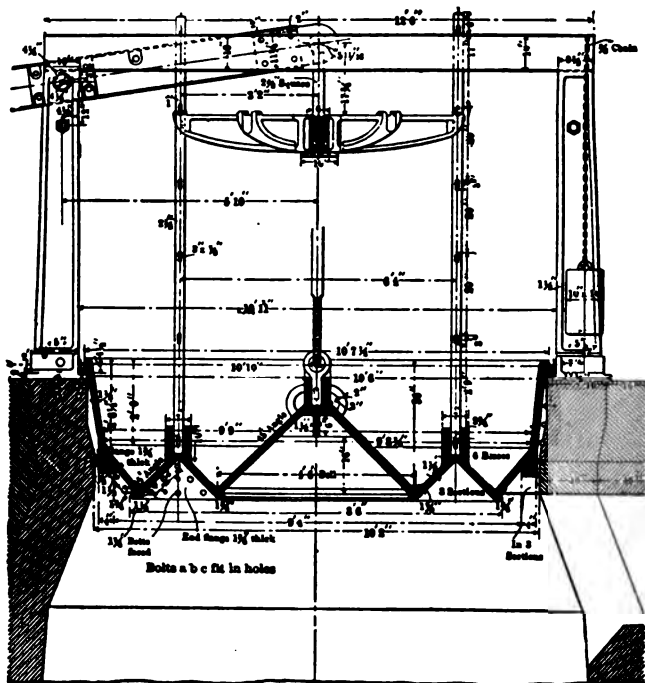


Fig. 32. Bauman double bell and hopper at the Saucon furnace, Hellertown, Pa.

while the one in the vertical center pipe is shown at the bottom of the "tee" which forms the junction between the vertical and horizontal pipes. The small amount of vertical movement necessary in the center pipe is taken up by these ball joints without any difficulty. The center pipe, with the plug fastened to it, is suspended from the tee by turn buckles, of which the one on the near side is clearly shown in the illustration.

In this type of top the lever which supports the bell can of course not be located in the center, and is therefore made double and takes hold of the bell at four points. See Fig. 34, which shows the construction used in Fig. 31 also. This type of top was used at the plant of the Longdale Iron Company practically throughout its entire life, and combined with careful hand-filling gave excellent results. The great

advantage of the double bell, over the single is that there are two openings of different diameters, which combined with the reversed slopes inside and outside the bell, permit the stock to be distributed more advantageously in the furnace than is possible under most conditions with the single bell. The latter is confined to a maximum of

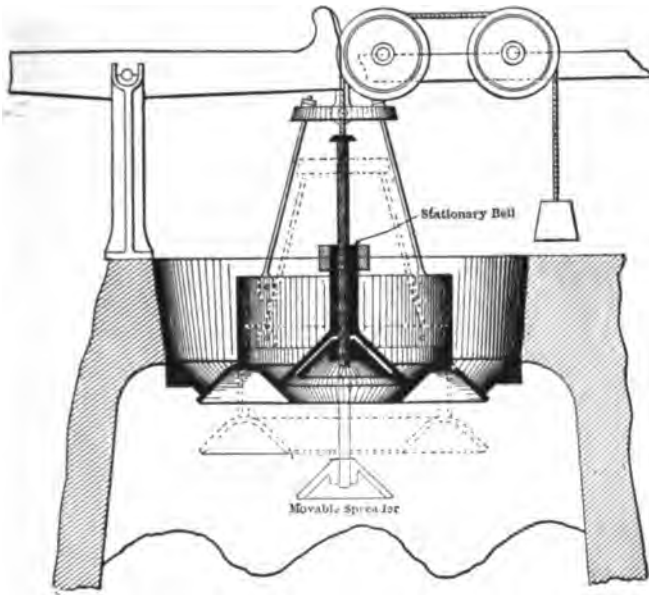


Fig. 33. The Witherbee double bell and hopper.

three annular areas of different sizes of material, and may give only two, whereas with the double bell there can be two rings of fines, and three of coarse material, thus permitting a better distribution of the gases over the whole area of the furnace, and exposing the stock to this influence much more effectively.

This top has been used at many other plants beside Longdale, and has been very generally commended by those who have used it, but it is undoubtedly somewhat more complicated than the single bell top, and that, with the extreme difficulty of proving the advantage of one or another method of distribution on the furnace unless one of those under consideration be very bad, has prevented its general adoption.

A still more radical departure from the standard single bell top is the Langen charger in which a central member like a "plug" seats downward in the bottom of the hopper to close it, instead of being pulled up from beneath, as in the standard type. The "bell," which is still so called in this case, is raised, to open it, instead of being low-

ered as is the regular bell. Frank Firmstone developed the double Langen charger in which the discharge took place around circles of two different diameters as in the Longdale double bell, but both openings were produced by raising the closing-pieces or bells, first one and then the other. He has described this top as applied by him at the plant of the Glendon Iron Company in the transactions of the American Institute of Mining Engineers, Vol. XIII.

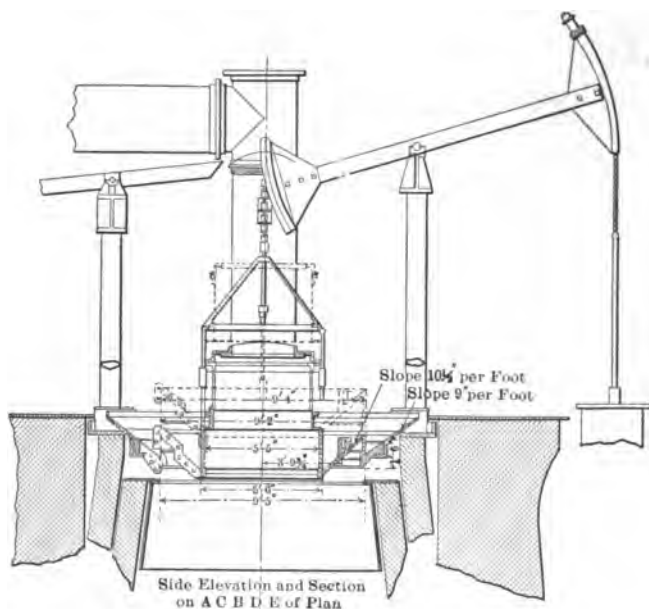


Fig. 34. Double Langen charger designed by Frank Firmstone for the Glendon Iron Works.

The top is well shown by Fig. 34, reproduced from this paper.

Excellent results were secured with these bells, but more care and skill was necessary in designing and operating them than with the ordinary single bell, and they have never had a wide use in this country, although bells of this type are still extensively used in Germany.

There is one important difference in the conditions under which these tops had their principal use and those which predominate to-day. This is in the size of the ore, which in those times was almost entirely lump comparable in size with the fuel, while now the ore is almost exclusively fine.

In order to have the gas travel uniformly through the stock it is very important to have the greater portion of the fines next to the walls, since with material of uniform size the spaces next to the wall are about twice as great in proportion as they are in the body of the

material, because when the high points of the individual pieces interlock with one another as they do in the mass of the material, the interstices are very largely filled, but when the high points come against a flat surface the interstices are preserved complete.

By taking spheres we can determine the amount of the interstices under each condition. We find that if there be a layer of spheres of uniform size arranged in close contact in equilateral triangles (the closest possible spacing) with another layer of like spheres resting in the low points of the first as they would arrange themselves naturally, the voids around the half spheres adjacent to the wall would be 65 per cent. of their volume, while those around the other half (away from the wall) would be 35 per cent.

This shows quantitatively the effect of the wall in increasing the interstices under conditions in which we can calculate it, and the general nature of the effect is the same in irregular materials.

It is an old tradition in the business that the fine material must be put against the walls, and it is obvious from these considerations that this is correct, and therefore the fines, that is the ore in modern practice, must go largely against the wall if we are to avoid excessive flow of gas there. Therefore we need now a single bell of rather large diameter in proportion to the stock line, but in the days of lump ores it was possible to carry this to an extreme and to have the charge column too open through the center and an excess flow of gas there, so it was desirable under those conditions to dump part of the charge in the center so that some fines would reach that part and help to obstruct it.

The Gas Seal. — For a long time after the introduction of the bell and hopper to close the top of the furnace no effort was made to prevent the escape of the gas during the time that the bell was opened for the introduction of the stock, but with the increased appreciation of the value of this excellent fuel it became more desirable to prevent even this waste, amounting to some 3 to 10 per cent. of the total gas produced, and for this purpose a secondary valve or seal was sometimes provided which was closed before the main bell was opened, and opened only after the main bell was closed.

One of the earliest forms of this apparatus consisted of a huge iron lid like a pot lid, which was lowered down on to the top of the hopper before the bell was opened, and raised again after the bell was closed.

The introduction of mechanical filling made the closing of the furnace top while dumping the main bell, easier and more desirable, and the obvious method of doing this was by the use of an apparatus similar to the air lock used in caisson work which in this case becomes a gas lock in which one valve opens from the outside into the lock, the other opens from the lock into the furnace. The bell having

so firmly established itself as the only valve worthy of consideration for closing the furnace top, it was perfectly natural that a similar bell should be used for the top valve of the gas lock, and this has become almost universal practice. This was the plan adopted at the Edgar Thompson Works, and in several other designs.

The development of the two-bell type of furnace top made the closed position of the gas seal bell the normal one, and this is greatly to be preferred because with mechanical filling it is possible to operate for a considerable period with the main bell leaking quite freely, if the gas seal be reasonably tight, and if it is closed in its normal position. But if the normal position of the gas seal bell be open, the leaking gas meeting the air burns up through the throat of the furnace and is likely to do great damage to all the mechanism, even to the extent of softening the rod of the main bell to the point at which it can no longer sustain the weight of the latter, thus causing its loss into the furnace, an accident involving a frightful amount of hard work and serious financial loss due to a shut down of from twelve to forty-eight hours, according to the style of top and the preparedness of the management for such emergencies.

With the gas seal bell normally closed it cuts off by far the greater portion of the leakage of gas and reduces it to an amount whose combustion can do but little harm. I have run a furnace for several days with a huge piece out of the main bell, because the hood and the gas seal being tight the quantity of gas which could escape was unimportant, but it would be impossible to operate a furnace in this condition if the normal position of the gas seal were open, because such a quantity of gas burning continually would destroy the furnace top completely. Even a much smaller leak is a very serious matter under these conditions; the result is that more work is required to keep the furnace top tight enough for safety, and main bells have to be changed more frequently because only small leaks past them can be tolerated.

Mechanical charging.—Many attempts had been made to use the skip for filling purposes as well as many other mechanical appliances, which would at least permit the elimination of men to dump the barrows at the top, since these men were usually the hardest worked, and always the ones with the greatest capacity for doing harm, by improper dumping. But the results of all these early attempts had been excessively unsatisfactory because the work of the furnace was so much poorer that increased fuel consumption, diminished output, lowered quality of product, and reduced life of lining amounted to very many times more on the debit side of the ledger than the slight saving of labor on the credit side.

In that early day it is well to note that the barrows were generally filled by hand shoveling, furnace operators having been exceedingly

slow in realizing the value of bins. The impression that the greater portion of the work of the bottom fillers could not be reduced explains why the early attempts at mechanical filling were directed mainly at eliminating the top fillers. This made the saving relatively small, while the loss due to bad distribution may easily be, in fact generally is, of enormous proportions, and may quickly convert a profitable into a bankrupt concern.

With the rapid increase in output which took place in the early nineties and culminated in the Duquesne revolution, the difficulties of filling the furnace became more and more serious. In addition to the vast difficulty of training and keeping crews of the size necessary to do this work by hand, and of supervising their performance of it to secure good furnace operation, it became almost a physical impossibility to handle the number of barrows required, and get them on and off of the hoist platform at the top and bottom of its travel, even though the operation was kept up at the highest possible pressure for twenty-four hours a day and practically without intermission. If any interruption occurred it became more and more difficult to "catch" the furnace after the stock line had gone down below the proper level; the fillers were kept almost up to their maximum speed to keep even with it under normal conditions and obviously had to make a stern chase in order to overcome any lead that it might get by an interruption in the charging.

The great expense of this method also became more and more obvious as the number of men required increased, and looking at the matter from the financial point of view it was well worth while to make an investment which would eliminate the labor of sixty men, while the same investment to eliminate the labor of only twenty might be a very poor one. In other words the annual cost was high enough to pay fixed charges on a heavy plant investment if a suitable means could be found for filling the furnace mechanically.

The necessities of the case were so great that renewed and more extensive efforts were made to solve the problem of stock distribution mechanically, and in the middle nineties a number of designs were brought out by various engineers for the accomplishment of this purpose.

There are two broad classes of mechanical filling as already described in Chapter II which may be broadly called "bucket filling" and "skip filling." There are several varieties of each, though the variations are much more matters of detail than of principle. It will be easier to discuss the points of the bucket system after considering the different types of skip filling, and we will therefore consider the latter first.

Skip filling. — The first installation of skip filling commercially suc-

cessful on a large scale was made at the Edgar Thompson Steel Works, under the supervision of its furnace superintendent, D. G. Kerr (now first vice-president, United States Steel Corporation), and chief engineer, E. E. Slick (now vice-president and general manager, Midvale Steel Company). By careful, painstaking and long-continued experimentation with model tops built exactly to scale, and raw materials crushed and sieved to the same scale, the proportions were found which would give a reasonably uniform and satisfactory distribution of the stock on the bell. A furnace was equipped with a filling apparatus of this design, and it was so successful that except for minor details nothing else has ever since been used at that plant, a record which I think is better than that of almost any other plant in the country, since many of them have tried out two or three, and others very many more types of tops.

A typical double-bell furnace top is illustrated by Figs. 35, 36, 37 in which the main bell and hopper, the upper or gas seal bell with the hood to connect the seat of the upper bell with the top of the hopper, and all the accessories of the top, including the skip, are well shown.

The upper bell does not need to be nearly so large as the lower one, since the diameter of the latter is controlled by the size of the furnace top into which it discharges the charge, but the charge will arrange itself on the main bell in very much the same way irrespective of the size of the upper bell. In fact small size is of decided advantage, since the nearer the stock enters through a mathematical point in the center of the furnace, the more uniform will its distribution be. If the upper hopper be large, and the stock be delivered into it irregularly by the skips, a greater or less portion of these irregularities will follow through the upper bell down into the lower. The larger the upper hopper the greater these irregularities may be, and the more completely they follow down onto the main bell, and so into the furnace.

Many plants have adopted what is known as the plain double-bell style of skip filling, but many have had most disastrous results with it, and others after the most careful and conscientious trials to obtain an exact distribution, have reached the conclusion that no form or design of this top is satisfactory because the distance which the materials travel is affected by the size, shape and moisture contents of the different materials and by the velocity of the skip when dumping. What is a perfect distribution on a dry day may be a frightfully bad one during a rain storm if the ore becomes wet, while a good distribution for a coarse coke, free from fine material, may give horrible results with a fine coke much broken up.

Various ingenious schemes have been used to eliminate or control these irregularities, and baffle plates without number have been tried and then discarded for the reason that no matter how good the results

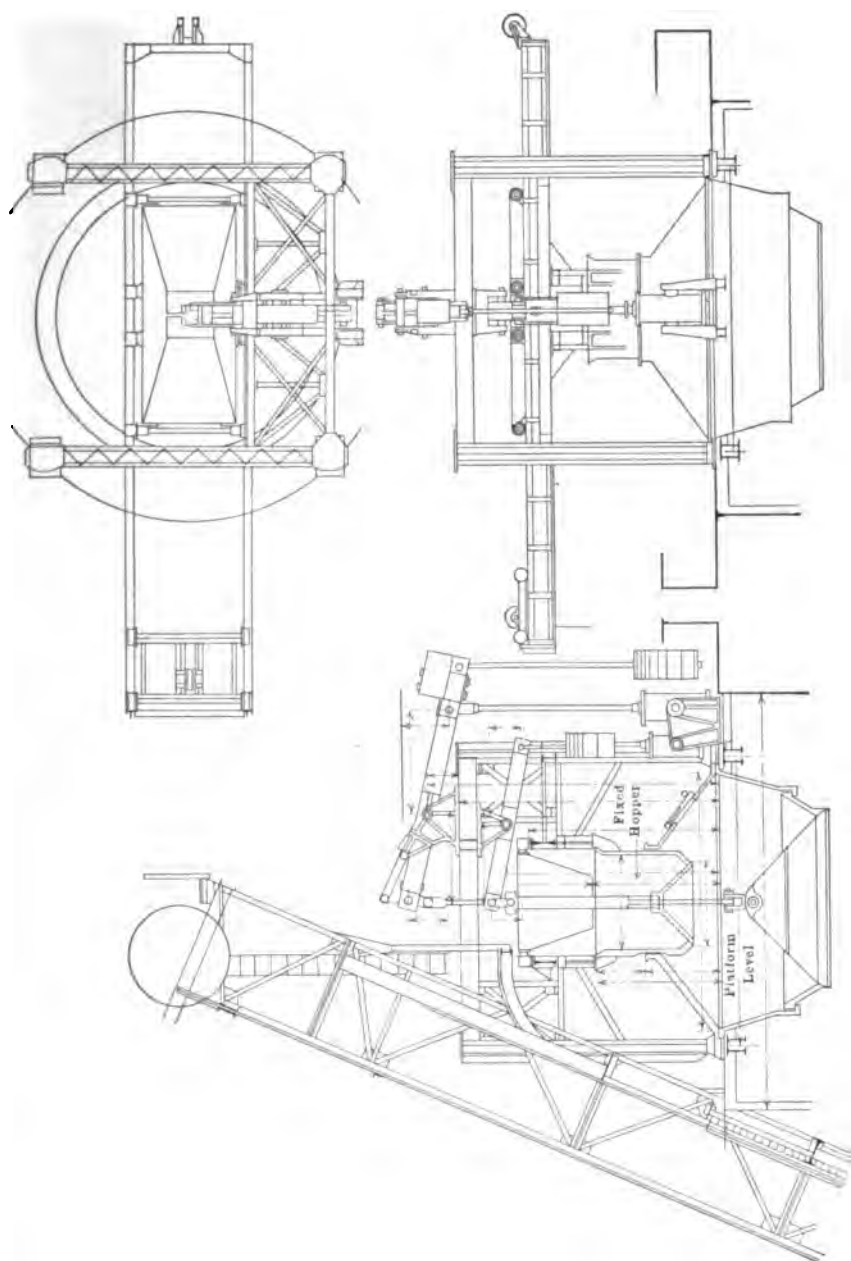


Fig. 35, 36, 37. Roberts non-rotating top with adjustable hoppers.

might be with one condition, they would infallibly be bad with some change in the conditions, such as was sure in ordinary operation to arise within a short time. Two of these attempts may be mentioned as showing the lines of endeavor.

The Roberts top. — The Roberts top designed by Frank C. Roberts of Philadelphia is shown by Figs. 35, 36, 37, showing a central section in the plane of the skip, a front elevation at right angles therewith, and the plan view showing the receiving hopper divided into two triangular pieces, more properly half pyramids, the hopper being a truncated pyramid with its axis in the center line of the furnace, and cut in two in the central plane between the skips. Each of these half-hoppers is mounted on four wheels resting on a stationary track at right angles to the plane of the skip. The treads of the wheels are wide, and their flanges set back well inside the line of the track so that the half-hoppers cannot only be moved in and out, but can also be slewed in the horizontal plane in order to secure that distribution which, under test, seems to give the best results. In other respects the design is similar to that of any other double-bell type of top.

The Rowe top. — The Rowe top was invented by a young man of that name at a plant where they had suffered greatly from bad distribution. The extreme simplicity of his design enabled it to be applied to the furnace with only a short shut-down, and this application resulted in an immediate and decided improvement in the practice. Unfortunately no drawing of this top is available, but it may be described without much difficulty.

A vertical plate was set up in the hopper immediately under the dumping position of each skip and in its central plane; this served to divide the skip load into two precisely equal halves. To this vertical plate were fastened inclined plates which ran down into the throat of the hopper, one of them sloping from the top corner next the skipway to the opposite bottom corner, and its companion plate on the other side sloping from the top corner farthest from the skipway to the diagonally opposite corner of the vertical plates, so that the planes of the two plates made a letter X, but one line of the X was on one side of the vertical center plate, the other on the opposite side. The bottom ends of the inclined plates were located approximately at the quarter points around the circumference of the throat leading to the bell. Consequently as each skip load came up it was divided into two halves, and those two halves placed on two adjacent quarter points around the throat; similarly when the other skip came up its load was halved and delivered to the other two quarter points.

It is obvious that this action would be but little affected by a change in the velocity of the skip in approaching its dumping position, or by changes in the size, stickiness, etc., of the materials, or at least

the changes so produced would be very much smaller than they would if the skips dumped directly and delivered all their material on one side or the other of the throat in accordance with variations in the conditions.

One of the earliest designs was that of M. A. Neeland, at the Ohio works of the National Steel Company, where the throat of the furnace was made quite high, and had set inside of it sloping vanes, roughly like a screw thread, which caused the material to whirl around as it descended through the throat, and as a result of this whirling a reasonably uniform distribution of the stock was obtained.

Very much may be done to secure regularity by correct proportioning of the main parts of the apparatus, the location of the skips in their dumping position, the size and shape of the receiving hopper which delivers the material from both skips alike to the throat, and many other details. Each has its effect on the general result, but while many devices such as those mentioned are available, it is far better not to trust to any of these alone but to eliminate the principal irregularities as far as possible by correct design in the first place; even then there will be plenty for the secondary devices to do to secure good distribution.

These irregularities were in several cases within my own knowledge very great. It did not require accurate measurement of the heaps and gaging of the size of the materials in each portion to show this; it was obvious to the most casual observer. The really remarkable feature of the whole situation was that many furnacemen did not recognize the source of their trouble or in some cases did recognize it, but were not allowed to correct it, because to do so would reflect on a design which had been selected by their superior officer.

At one plant using lump ore which I visited about ten years ago I was taken up to the top of the furnace by the stock-house foreman. Of the skip load which lay on the upper bell about two-thirds lay on the side next the skipway and consisted of all the finest portion of the load, while the one-third on the opposite side contained all the coarse! The stock-house foreman said he thought that gave a very good distribution, and when I casually asked him where the "hot spot" was of which he had told me he pointed down directly in the line of descent of the coarse material.

Breakage of the coke. — One of the most important factors in the whole subject of furnace operation was overlooked in the early designs of mechanically filled furnaces. This was the question of breakage of the coke. In some plants this seemed to have been almost totally disregarded. Coke was dumped from hopper cars on high trestles into bins perhaps almost empty, involving a drop of 15 to 35 feet, dropped again from the gate of the bins to the bottom

of the scale car or bucket, 6, 8 or 10 feet more, dropped from the scale car into the skip, a distance about the same as the last, from the skip into the receiving hopper some 7 or 8 feet, from the upper bell on to the main bell, about an equal distance again, finally from the main bell on to the stock line, some 8 or 10 feet, if the furnace were full, and almost any distance if it were empty.

The detrimental action of fine coke in the furnace, and its much reduced fuel value, particularly for heat in the hearth, are well known, and need not be further stressed here though apparently they were overlooked by some of the furnace designers of fifteen years ago. Just how much the coke was broken up, how much the average size of the individual pieces was reduced, and what percentage of detrimental fines were made by this treatment in extreme cases, we shall never know now; perhaps it is just as well that we should not. But the general result was seen in the fuel consumption, and eventually in the cost sheet of many of these plants, while the furnace manager, who in most cases was not responsible for the design, spent many unhappy hours over these conditions, for which he had in many cases to take the blame.

It will be noted that with the Duquesne system, presently to be described, the buckets were so designed as to come close up under the bins with only a short spout beneath the gates of the latter. This reduced the drop into the bucket to the minimum, and eliminated two dumpings of the coke as compared with those plants where it was transferred first to the scale car, and then to the skip before reaching the upper bell.

It is altogether possible that this feature had an appreciable influence in bringing about the early success of Duquesne as compared with many of the skip-filled furnaces built soon afterward. Now furnace managers and engineers understand this matter of coke breakage better, and it is recognized that no top should be permitted to give the coke an inch more drop than is absolutely necessary to accomplish the transfer of the stock.

In more recent years the "shatter test" of coke has been invented and attention is paid to the strength of the coke, so that more is known as to the injury done it by any given drop, but with this advance has gone the increasing realization that every unnecessary foot of drop was highly objectionable and could not fail to cause some proportionate share of increased coke breakage.

As a consequence the enormously long throats which were used on some furnaces fifteen years ago have disappeared, and one of the major considerations of the present day in regard to any system of filling is its probable effect on the coke. Considering all these important points which were largely if not wholly ignored or neglected, the only wonder

is not that furnaces did bad work in the early day of mechanical filling, but that they ran at all.

Rotating tops.— If the location of a given irregularity be rotated through an angle increased by a definite amount at each charge, we shall obviously obtain the equivalent of spiral hand-filling and so by evening up over a number of charges the kind of material delivered to each portion of the furnace circumference, shall secure the equivalent of uniform filling in each charge. Furnace tops which operate on this principle are called rotating or revolving tops.

There are in use three principal types of rotating tops — the Brown, the Baker and the McKee. All of these are patented, and the whole subject has been one of much complexity, not only technical, but to some extent legal. The merits and demerits of the different types of apparatus have been the subject of acute and heated discussion. Each of them has been thrown out of use at one or more plants, and it is therefore necessary to admit that there are objections to all of them. To state these objections as well as their advantages fearlessly and firmly is the only course open for a satisfactory treatment of this subject; this will be my aim however far short of this object I may come.

The Brown top.— Although I have referred to the persistence of hand-filling as almost universal up to the time of the Duquesne revolution, it is a fact that the first reasonably satisfactory apparatus for mechanical charging had been introduced several years before. The skip which dumps by turning nearly upside down, as described in the second article of this series, has been known for a long time. I am told that it was used two hundred years ago in Sweden. An attempt was made to use skip filling by Fayette Brown, the father of the late Alexander E. Brown. It is said that the furnace so filled worked irregularly in the way in which so many such furnaces have done, and the skip was therefore thrown out. In order to secure symmetrical distribution with hand-filling it occurred to Fayette Brown to put a cover over the entire hopper with a single opening through it large enough to admit of dumping only one barrow, and at a certain definite location. This cover was revolved about the axis of the furnace by a mechanism driven from the hoist sheaves, so that this opening advanced one dumping space at each revolution. This, of course, forced the top fillers to dump correctly.

Many years later it occurred to Alexander E. Brown to combine this controlled system of dumping with the skip hoist by having the skip deliver into a central hopper with an outlet spout on one side, and revolving this hopper and spout around the vertical axis of the furnace by a mechanism driven from the hoisting sheaves. This is the essential principal of the "Brown top," at least one of which was in

operation several years before the Duquesne revolution, and has, I think, continued in operation from that time to this.

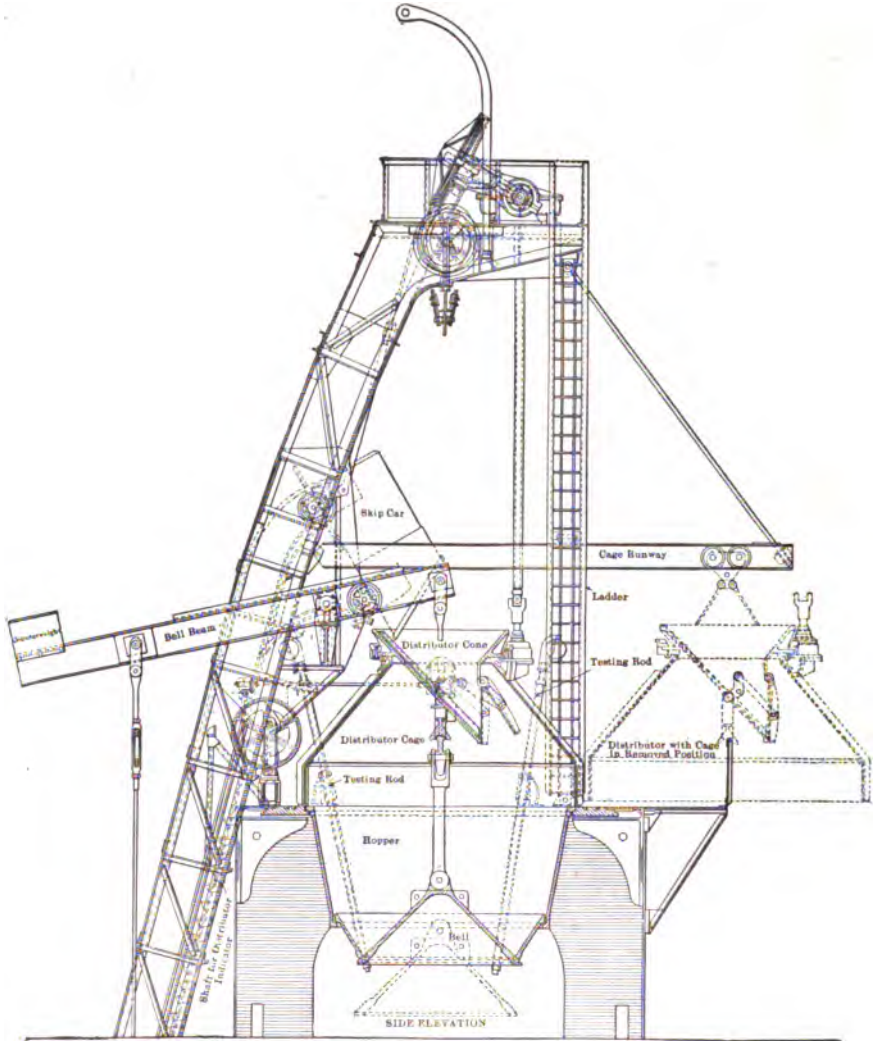


Fig. 38. Brown Rotating Top.

This top as now built is shown by the line drawings, Figs. 38 and 39, and by the photographs, Figs. 40 and 41. At the bottom of the line drawing are shown the bell and hopper; above these, on the top of the furnace proper, is the conical gas seal which acts as a support for the revolving distributor and the gears which drive it. Above the hopper is seen the skip in its dumped position, and at the top the main rope sheave, with the gears through which it drives the vertical

shaft descending to the gear box just outside the distributor cone, through which the latter is revolved. The detail of the sheave and the upper gears is shown in Fig. 39.

The gas seal consists of a flap valve on the spout of the receiving hopper whose normal position is open, as shown in full lines in Fig. 38, but which is closed by the first portion of the movement of the main bell, acting through the bell crank shown in dotted lines. This gas seal is not so tight as a bell and is subject to the objection above described, that its normal position is open, so that if the main bell is leaking to a considerable extent the gas can rise through the spout and burn almost without interruption around the upper portion of the top mechanism.

There is a ratchet in the mechanism which drives the hopper when the sheave runs in one direction, but allows it to stand still when the sheave runs in the opposite direction, on the return trip; thus the hopper is rotated a definite amount with each trip of the skip.

At this point Mr. Brown introduced into the design an admirable feature. Instead of having the distributor rotate through an angle commensurable with 360 deg., so that it would always return to the same position at the end of every complete revolution, he designed it to revolve two or three degrees more or less than a quarter of a revolution, so that at the end of four movements it is about ten degrees one side or the other of the point at which it started, and only after many revolutions, representing a great number of charges, does it return to its initial point. This has the great advantage of giving not only each segment, but each fraction of the circumference of the furnace exactly the same treatment, and this is greatly to be preferred to any system which must always use the same starting point, since in that case any irregularity due to the difference in shape of the first skip load dumped and the last, or the like, is localized in one place and may cause serious trouble, whereas if it went to each point of the circumference in turn it would do no harm.

Any mechanism at the top of the blast furnace has to operate under extremely difficult conditions. It is necessarily surrounded by the dust arising from the different components of the charge, which is sharp, gritty, and destructive to the last degree, and is exposed to

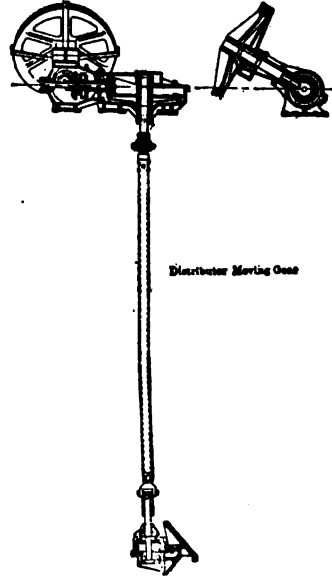


Fig. 39. Rotating Gear for Distributor.

temperatures not infrequently above those at which lubrication is possible, and if there be a leak of the main bell so that gas escapes at all freely, the apparatus is entirely likely to be subjected to direct flame. These conditions are so severe that they alone have caused the defeat of many tops, and in the early days they undoubtedly caused many mechanical difficulties in the operation of the Brown top.



Fig. 40. Brown Top removed from furnace.

With the passage of time many of the features of the design which caused these difficulties have been overcome, and in the North where furnace tops commonly work at quite low temperatures, about 400 deg. or below, these mechanical troubles have not been so severe, but in Southern practice, with greater coke consumption, and much hotter top conditions, the Brown top has in more than one instance been discarded for the purely mechanical reason that it could not be kept in successful operation, the situation frequently being complicated by the fact that mechanics of sufficient skill to operate a mechanism of this kind successfully were, in past years, scarcer in the South than in the North.

In addition to these mechanical difficulties of operation the Brown top in spite of its appearance of perfect symmetry does not give an absolutely symmetrical distribution.

An examination of Fig. 28 will show that the line of the distributor in the position drawn is practically a continuation of the line of the bottom of the skip, so that the material discharging from the latter has only



Fig. 41. Brown top on furnace.

to continue on its way straight through the distributor, and is thereby delivered from it with velocity practically unchecked. But when the discharge spout of the distributor is in the position opposite to that shown, its slope is almost at right angles to the line of discharge from the skip, and material delivered upon it is therefore brought practically to a standstill, and starts again virtually from rest, so that its velocity of delivery from the distributor is very materially less from this position than from the position opposite. The result is that the material is thrown considerably further out in the hopper with the distributor in the position shown, than in its opposite position.

Moreover, when the spout of the distributor is at right angles to the position shown, another effect comes in. The spout is not a mathematical line, but is necessarily a broad opening to permit the escape of the stock under any and all conditions, and to pass pieces of scrap of considerable size. The material discharging into the hopper from the skip has a very considerable horizontal component to its velocity when it strikes the distributor, and instead of discharging down the axis of the spout, this horizontal velocity takes it over to the far side of the spout, whether the latter be turned toward or away from the observer.

The effect of this is, of course, to put more material on the side of the bell opposite to the skip than on the side next to it. In other words, in spite of the central location of the axis of the distributor the horizontal velocity of the stock imparted by the skip persists to some extent and carries the center of gravity of the pile of stock, as it rests on the bell, considerably beyond the axis of the furnace. That is, the side of the furnace next the skip receives a considerably smaller portion of every charge than does the opposite side. Unsatisfactory furnace work has been traced directly to this cause in several cases.

The Baker top. — This may be considered as a modification of the Brown top in that it distributes the material in heaps on the main bell. It is shown by Fig. 42. Endeavor has been made in the design of this top to overcome the mechanical difficulties due to the great weight of the rotating parts, the large radius of the sliding surfaces in the Brown and the somewhat complicated mechanism required to drive it, and also to reduce to a minimum the height from which the coke is dropped so as to reduce coke breakage. The main bell, hopper, and lip-ring are clearly shown by the drawing, and are of standard construction, but, as is necessary in most central types of stock distribution, the main bell is not supported on a single central rod; instead it is hung to the center of a horizontal equalizing beam from the two ends of which rods run up to the ends of the double main bell beam. A section of the equalizing beam, with its sharp-edged top to divide the current of stock, and prevent any disturbing action on the descent of the latter, is plainly shown on the drawing. The main bell rod on the far side is shown broken away below the top of the upper hopper, but a short piece is shown attached to the end of the main bell beam.

In this design there is a gas-seal bell practically identical with the upper bell of the ordinary non-rotating double-bell charging apparatus, but in this case the bell has fastened to it a plate which is elliptical in outline and is set parallel to one side of the conical surface, and constitutes a sort of slanting piston working in the receiving hopper, which is nearly cylindrical, flaring slightly at the top, as shown in the

drawing. The upper bell is rigidly keyed to the lower end of its (central) bell rod. By means of this rod the bell with its extension plate attached is rotated through a certain angle each time it is raised

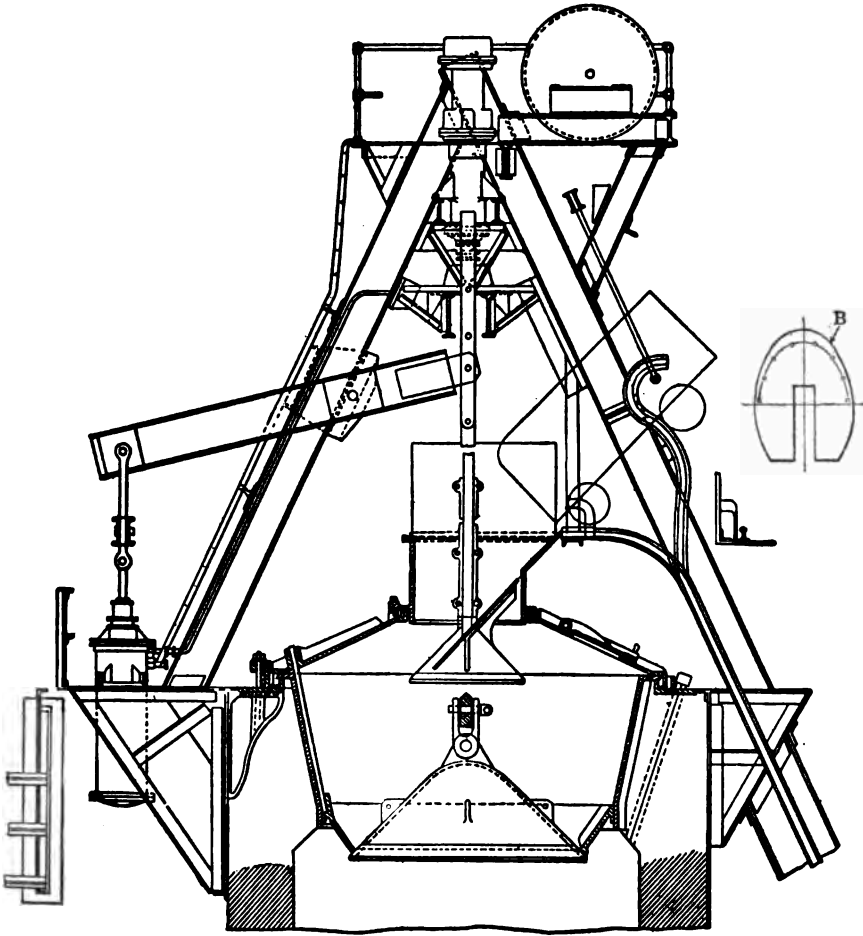


Fig. 42. Baker rotating top.

and lowered. When the upper bell is open, and in the position shown, the plate acts practically as a continuation of the lip of the receiving hopper and discharges the entire skip load on the opposite side of the furnace. The upper bell is then closed and opened again, which brings the deflecting plate into a position in the horizontal plane approximately to right angles of that shown. This delivers the next skip load on to the bell practically at right angles to the first one, the third is approximately opposite to the first, and the fourth practically

completes the cycle, but if the "hunting tooth" effect used by Brown is desired, the completion of the cycle does not bring the deflecting plate back exactly to its initial position.

Instead of an arrangement of gears for rotation, recourse is had to what is known as the rifle-bar cylinder. This device has been in use for many years for rotating the bits of rock drills. The cylinder which operates the upper bell is immediately over it, and inverted so that it operates directly without the intervention of levers or other devices, which makes an extremely simple design.

The operation of the rifle-bar cylinder is shown by Fig. 43. The piston carries two helical vanes A which work in corresponding grooves or threads in the nut B which has ratchet teeth cut in its upper surface. These are engaged by vertical gravity pawls D in pockets spaced around the cylinder. They prevent the rotation in one direction of the nut B. A square opening at the top of the chamber on which the helical vanes are cast is an easy sliding fit on the square rod E, which carries on its top a circular plate F, to which it is rigidly keyed, and which has on its top surface ratchet teeth engaging with pawls G exactly the same as those of B and operating in the same direction.

On the down stroke of the piston, the action of the vanes forces either F to turn to the right or B to the left, but the ratchets G do not allow F to turn to right while the ratchets D do allow B to turn to the left, which it accordingly does. On the up stroke the pawls engage with the ratchet teeth C and prevent the backward rotation of B which thus compels the rotation of the disk F in its turn.

Thus every cycle (up and down stroke) of the movement of the piston forces the bell and deflecting plate to rotate through a given angle. The amount of the rotation is determined by the pitch of the helical vanes, and the stroke of the cylinder. The latter is intended to be constant and therefore the angle of rotation of the upper bell with its deflecting plate is also constant.

The upper portion of this cylinder has no function except to enclose the apparatus and prevent the entrance of the grit and dirt which always abound on top of furnaces, and which have done so much to destroy charging mechanisms. The cylinder is virtually a single-acting one, since the weight of all the parts acts downward and suffices for the down stroke, steam being used only for the up stroke and to cushion the down stroke.

This type of top has given good satisfaction at a number of plants, but its use has been abandoned at a number of others, since it was claimed that the benefit obtained from its form of distribution was not sufficient to offset the possibility of the small bell being stuck with its deflecting plate in one position, and dumping the stock to one point on the main bell continuously for a number of charges, or even

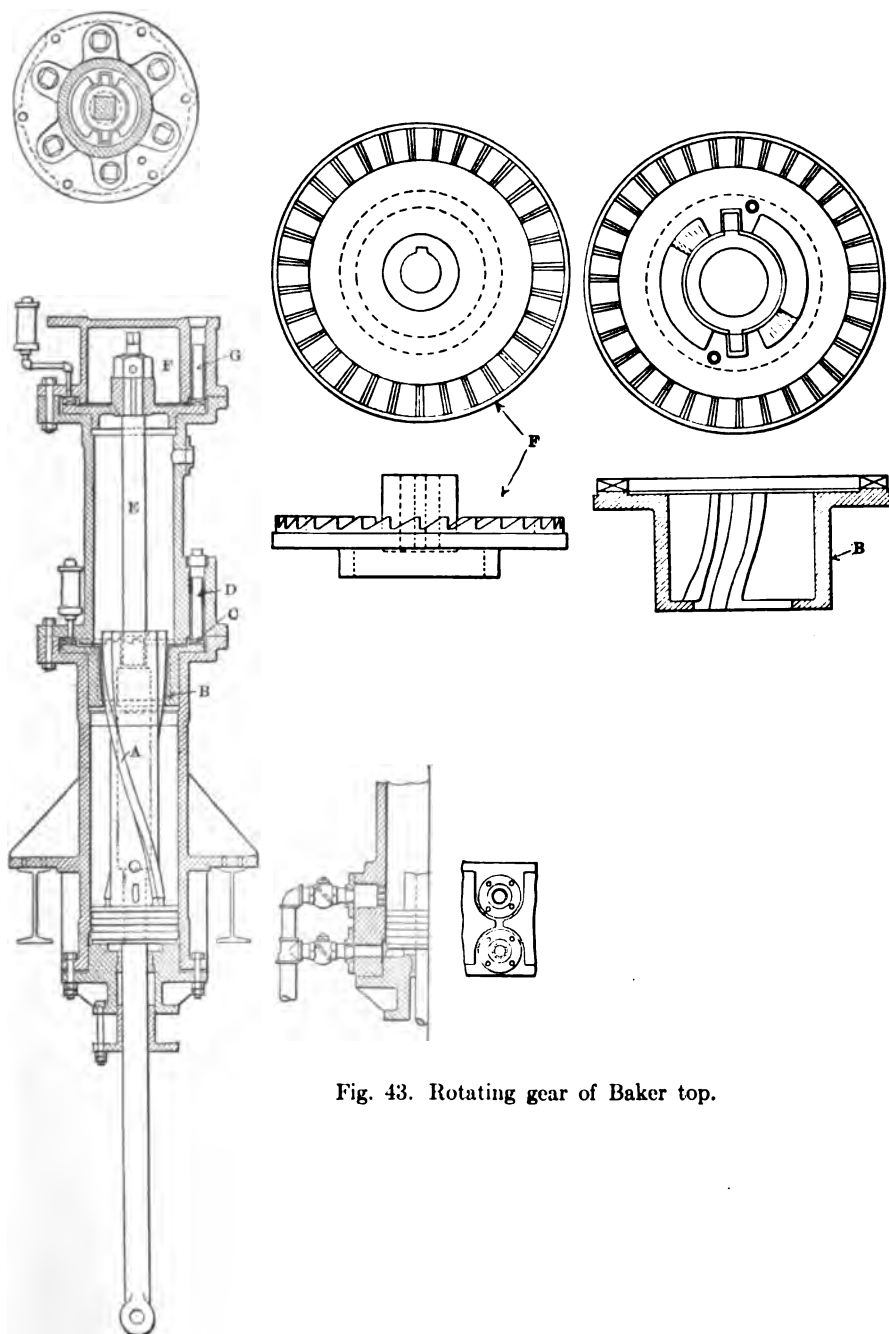


Fig. 43. Rotating gear of Baker top.

hours, if this condition was not discovered. For it is evident that if the small bell fails to operate between skip loads the position of the deflecting plate will be left unchanged, while there is nothing to prevent the indefinite continuance of dumping in this position. This, of course, would make the worst possible type of stock distribution, and would ruin the work of any furnace in a very few hours.

There is with this design the possibility of jamming the deflecting plate against the wall of its slightly tapering receiving hopper by the entrance of lump material back of the plate, and while the probability seems slight, this chance, in addition to the discarding of the top by at least one large plant, has proven sufficient to reduce its popularity. It is probable for reasons which will appear later that the top has been successful at plants using lump ore, or a mixture of lump and fine, and less successful at plants using all fine ore. This is in accordance with the facts in regard to the use of these tops. Those within my knowledge at plants where the ore mixture is lumpy have given far greater satisfaction than those in the Lake Ore district.

The McKee top — It has been very widely believed by many furnacemen, and is even yet, that one of the essential characteristics of a revolving top is that if the revolving apparatus ceases to work it should still continue to give a reasonably good stock distribution. This means that dumping in heaps is barred because, as explained in regard to the Brown and Baker tops, if they cease to rotate they give the worst conceivable distribution. This then implies that the stock must be dumped in annular layers as nearly uniform as possible, and that only irregularities in the layers due to the irregular discharge by the skips into the receiving hopper should be eliminated by revolving the latter.

This idea seemed to have occurred almost simultaneously to various engineers, but the credit for having first applied it successfully undoubtedly belongs to Arthur G. McKee of Cleveland.

The earliest form of this top consisted simply of a conical receiving hopper into which the skips dumped, terminating in a hopper of steeper slope below whose bottom was closed by an ordinary gas-seal bell operated through a hollow bell rod which encircled the main bell rod. The hopper was mounted on ball bearings set well back from the line of the hopper, and carefully designed to keep the dust out from above, and give it ample opportunity to fall out below, holes being drilled at intervals in the bottom of the ball race to facilitate the latter purpose.

The gas-seal bell, of course, has to rotate with the hopper and therefore the hollow bell rod is provided with a small ball bearing near its upper end to permit its lower part to rotate with the small bell without interfering with the operating mechanism above.

Probably one of the most important features of the design in operation is the extension of the ball track to a path well outside of the closest point on the hopper, which is carried by radial arms extending in from the upper ball race. This makes an air space between the ball race and the hopper so that unless the latter be heated to a red heat or above, the ball race still remains relatively unaffected and able to perform its functions.



Fig. 44. Kennedy top.

This apparatus is not driven by the rotation of the sheaves through ratchet wheel and gears as in the Brown, but is provided with an independent electric motor operating through reduction gears, and controlled from the operating platform at the bottom of the furnace.

The general appearance of this early form of this top is shown by Fig. 44, which, however, is not a McKee top, but a top designed by Julian Kennedy of Pittsburg, on exactly the same principle as the McKee, but rotated by a wire rope passing around the hopper and down to the ground level, where it is moved by hydraulic cylinders or other suitable mechanism to give the desired rotation to the hopper. In principle the design is in all respects similar to the McKee.

In the McKee top contacts are attached to the hopper at four

points and by means of wires carried down to the operator's platform these light indicator lamps when they come into certain positions.

In operating this first design a skip was dumped into the hopper, which was then rotated through ninety degrees. The second skip was then dumped and the hopper again rotated, and so on to the fourth skip load which completed the cycle, the upper bell was then opened, permitting the charge to descend onto the main bell from which it was dumped after the upper bell was closed. The process was then repeated.

Almost innumerable modifications of this system were designed to eliminate certain irregularities which briefly are the same as those I have pointed out in connection with the dumping of barrows into the hopper in hand-filling. The location of the first skip load in the hopper and the room it occupies is very different from that of the second and third, and still more different from that of the fourth, which is likewise different from that of the second and third. Moreover, with the double skip there was a serious irregularity which does not appear from the examination of a side elevation of one of these tops. From this it might appear that both skips dumped in the central plane between them, but as a matter of fact one dumps well on one side, and the other as far on the other side of this central plane, so that two successive loads are a considerable distance apart in the hopper irrespective of its rotation. It will be obvious on a little consideration that when this distance is combined with that arising from the constant angle of rotation, two adjacent skip loads may be the sum of these two distances apart, and the next two only their difference, with consequent great variation in the shape and location of the resulting heaps.

Many furnaces equipped with tops of this type, while they apparently had a good stock distribution, gave extremely poor results, and as furnaces working under very different conditions gave similar results along certain lines, which were not nearly so noticeable with any other type of top, it seemed reasonable to assume that the trouble was due to this type of distribution.

The furnaces filled in this way scoured out their linings in a zone twenty or thirty feet above the tuyeres, not on one side as so frequently happened with non-rotating skip-filled furnaces, but quite regularly all around. The blast pressures were high, furnace control unsatisfactory, and fuel consumption apt to be excessive.

The real reason for these results has, so far as I know, never been worked out, but my experience in one case proved that they did exist and that they were directly chargeable to the type of distribution system. The proof of these facts was so convincing and the result obtained by eliminating these conditions so remarkable that they must necessarily carry conviction to the mind of any unprejudiced furnace-man. I shall revert to this phase of the subject later.

It was in order to overcome these difficulties, whatever their reason may be, that Mr. McKee has in recent years redesigned his top so as to eliminate some of the worst irregularities. The new design is shown diagrammatically by Fig. 45.

The original rotating conical receiving hopper is entirely eliminated and is replaced by a stationary receiving hopper triangular in front elevation through which each skip load in turn passes into the cylin-

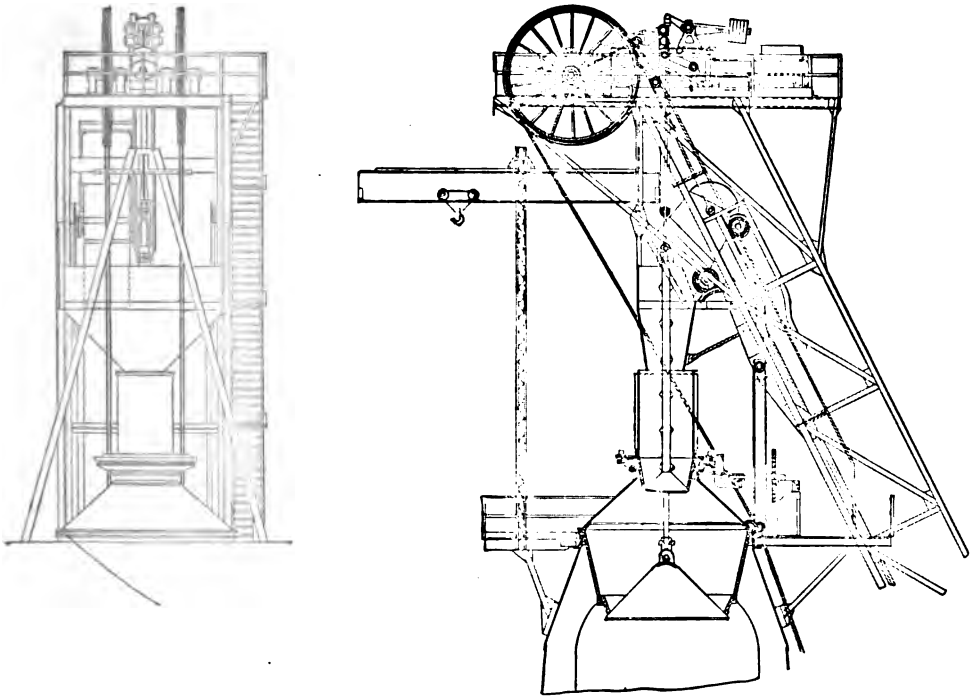


Fig. 45. Recent design of McKee top.

drical rotating hopper below. This has the great advantage of practically centering the charge to begin with, and thereby eliminates some of the worst irregularities of the original design.

The revolving hopper is now being rotated preferably to six points instead of four, and so equalizes any irregularity which may occur in the discharge of the skip load into the hopper, by throwing it to each one of the six successive radial positions in turn.

The design of ball races carried well away from the hopper proper, the provisions for preventing the entrance of dust and for allowing it free exit are maintained substantially as they were in the earlier design. It is no more than fair to say in this connection that mechanically this top in my experience gave a minimum of trouble, and I think that this experience has been quite general. I have not operated any furnaces

with the improved design, but my information is that many of the troubles which prevailed with the older design have been diminished with this, and that the results are very much better, as is to be expected from the removal of the irregularities due to the varying distribution of the skip loads around the conical hopper.

The bucket system of distribution. — When the Duquesne furnaces were designed, as I have previously explained, practically all the traditions of blast-furnace design were discarded and the engineers struck out on lines boldly new in almost every direction. This was true in regard to the filling system which was invented for that plant by M. A. Neeland, then chief engineer of those works.

When the plans for the plant were started there were only two mechanically filled furnaces running, one with the Brown top at Sharon, previously mentioned, and one at the Lucy furnaces with the upper hopper closed by an "orange peel" which their superintendent recommended be *not* adopted.

A set of drawings for a skip-filling system had been made, but when Mr. Rotoff (since deceased) came to the plant to be superintendent of the furnaces which it was proposed to build, he rejected this design absolutely as he had had experience with the very unsuccessful skip-filled furnace at the Lucy plant where the segregation of the lumps and fine had manifested itself very clearly and had demonstrated how completely it could prevent the satisfactory working of the furnace.

The top now to be described was designed by Mr. Neeland to overcome this difficulty, and it has been very successful in doing so. To accomplish this result he decided to use a type of bucket for hoisting the material which could be accurately centered on the furnace top before dumping, and then be dumped uniformly in all directions.

The huge bucket used has its bottom closed by a bell the central rod of which suspends the whole from the truck which runs on the inclined hoist. The general arrangement is shown by Fig. 46.

The scale cars on which the buckets are set run along under the double row of bins from which the buckets are charged with the required material. Each bucket in turn is then brought into the central plane of the skip where it is picked up by the hook on the inclined truck (Figs. 47 and 48) and carried to the top of the furnace. There the front end of the truck, with the bucket hanging to it, enters a vertical slide in the center line of the furnace top and is lowered vertically to a seat over the top of the gas seal. The further downward movement of the slide lets the bell bottom of the bucket pass down inside the gas seal, carrying the counterweighted gas-seal bell with it. The bucket then discharges and the return movement of the slide raises the bell bottom of the bucket back to place, allows the gas seal to be seated by its counterweight, and finally picks up the bucket itself

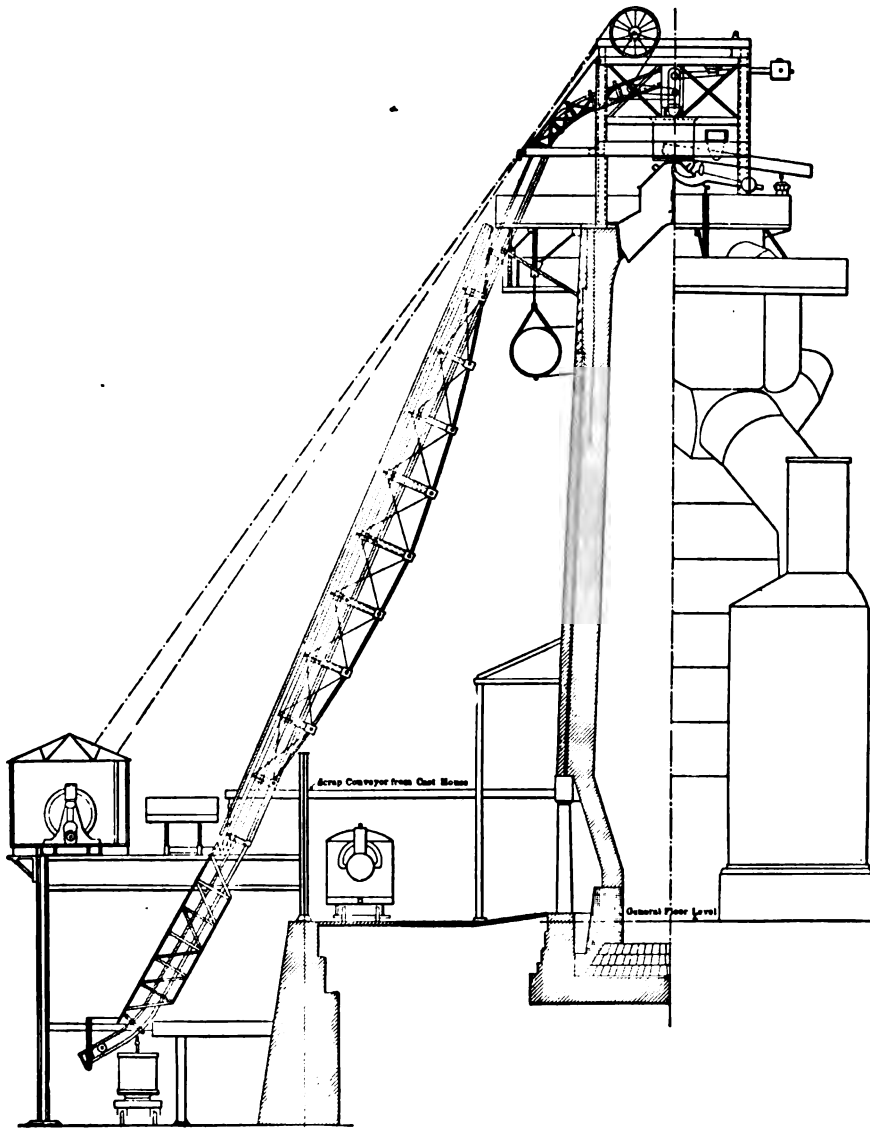


Fig. 46. General arrangement of Nealand top.

on its own bell, and the return trip of the truck takes it back to the bottom where it is unhooked and another loaded bucket picked up. The arrangement is well shown by Figs. 49 and 50 which show the bucket resting on its seat in the furnace top and its bell on top of the gas-seal bell.

It will be seen that there is no horizontal velocity whatever to the stock, and that if it is reasonably level in the bucket an equal amount

is discharged on each sector of the bell. It is, in fact, as if the hopper of the double bell top were filled under the bins, brought up to the top of the furnace and dumped, instead of being filled by the intervention of the skips. It is worthy of note that the bins are arranged in parallel rows on each side of the scale-car tracks so that the buckets are filled alternately from opposite sides, thus balancing up the irregularity which would have arisen from the great segregation on one side of the bucket had it been filled always from one side. At the same time

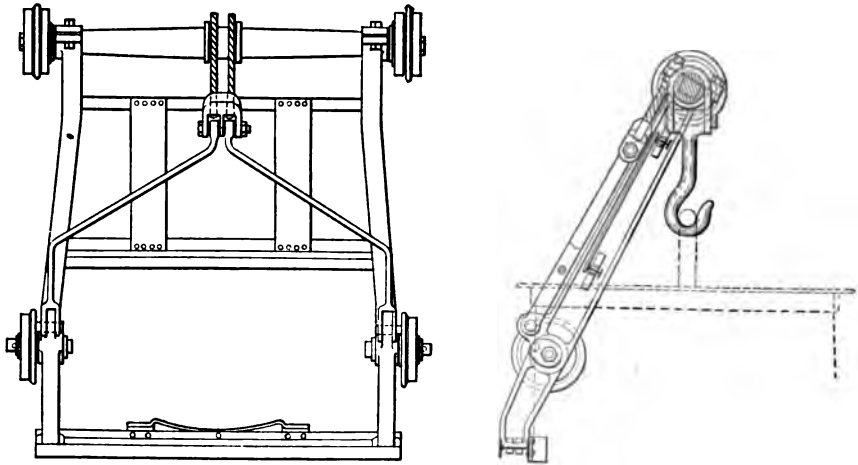


Fig. 47, 48. Bucket carriage of the Neeland top.

it is no more than fair to add that Mr. Neeland had this matter of segregation very much in mind, and he designed the bins with the shortest possible chutes to give a low delivery velocity and so arranged that the stream of material strikes as closely as possible on the apex of the bell bottom of the buckets.

In more recent years this system of filling has been improved by the addition of a motor on the scale truck which rotates the buckets either through a certain definite angle after they have been filled, increasing by a fixed amount for each bucketful, as for instance 90, 180 and 270 deg., or else the buckets are rotated continuously, while charging, so that the charge may be distributed in uniform rings, thus securing an equable distribution of lumps and fines in every portion.

Ford-Parkes top. — Various modifications of this type of filling system have been made. A general drawing of the Ford-Parkes design was shown in the previous chapter. The details of the top and bottom are shown by Figs. 51, 52, 53 and 54. The buckets in this design are not delivered on to a scale car, but on to a turntable carrying four bucket seats. This table is rotated 90 deg. at a time, and this rotation takes the empty bucket away and brings a freshly filled one to take

its place. When the bucket is at 180 deg. from the position under the skipway, it is filled from the scale car which in this case is the regular hopper type of scale car. The general arrangement of the turntable and the motor for turning it are also clearly shown, also the scale car in position in Fig. 52.

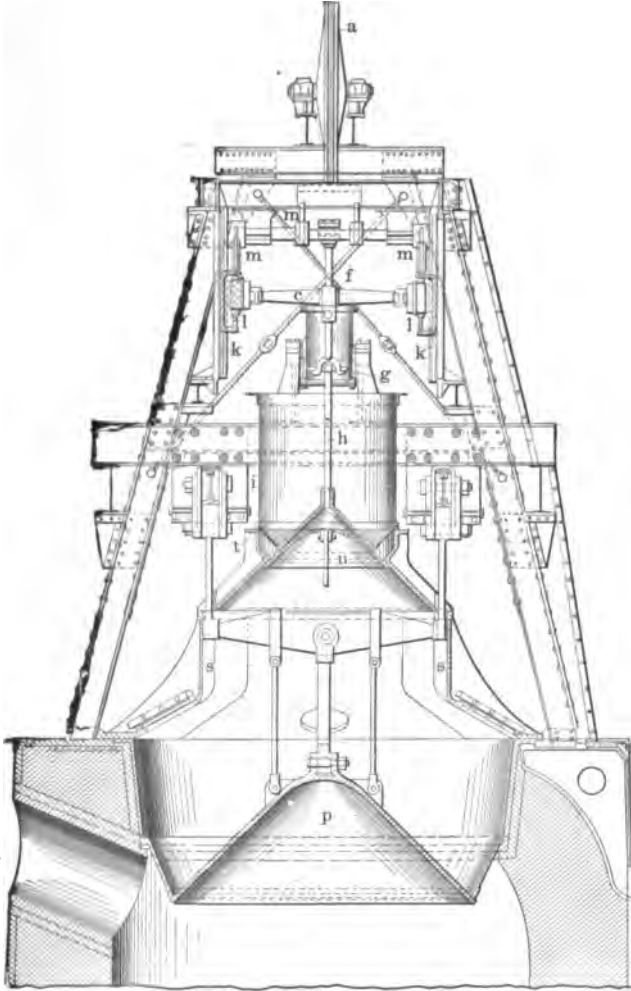


Fig. 49. Details of Neeland top, front elevation.

The general design of the bucket-carrying truck is shown at the foot of the incline, the large quadrant at the front or upper end of the truck, from which the pickup hook hangs, is clearly shown. This quadrant is rigidly attached to the rear wheel of the truck and pivoted on its own center in the center of the equalizer between the two front

pairs of wheels. It is evident that if the rear wheel of the truck be swung up around the pivot as a center, that the hook carried by the chain unwinding from the quadrant must move vertically downward.

Referring now to Fig. 30, showing the top of the incline, there will be seen the convex curve on which the two front pairs of wheels of the truck run, and above a guiding slot with a sharp reverse curve

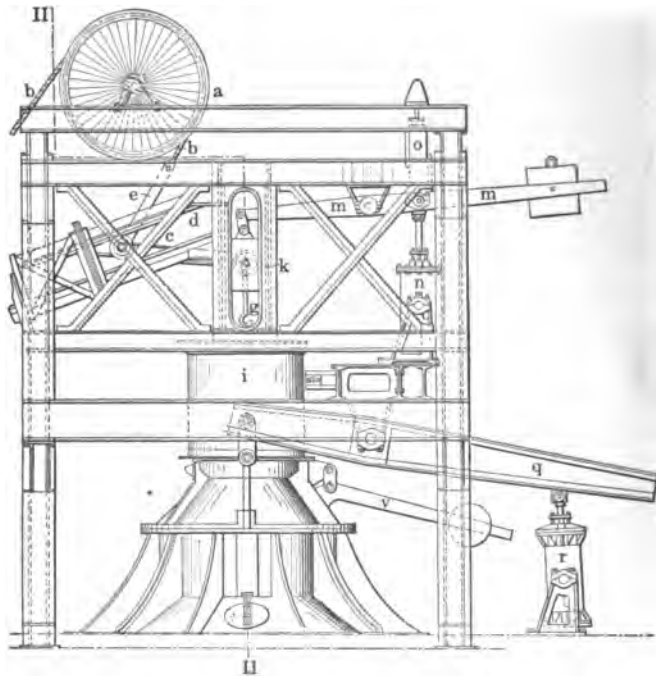
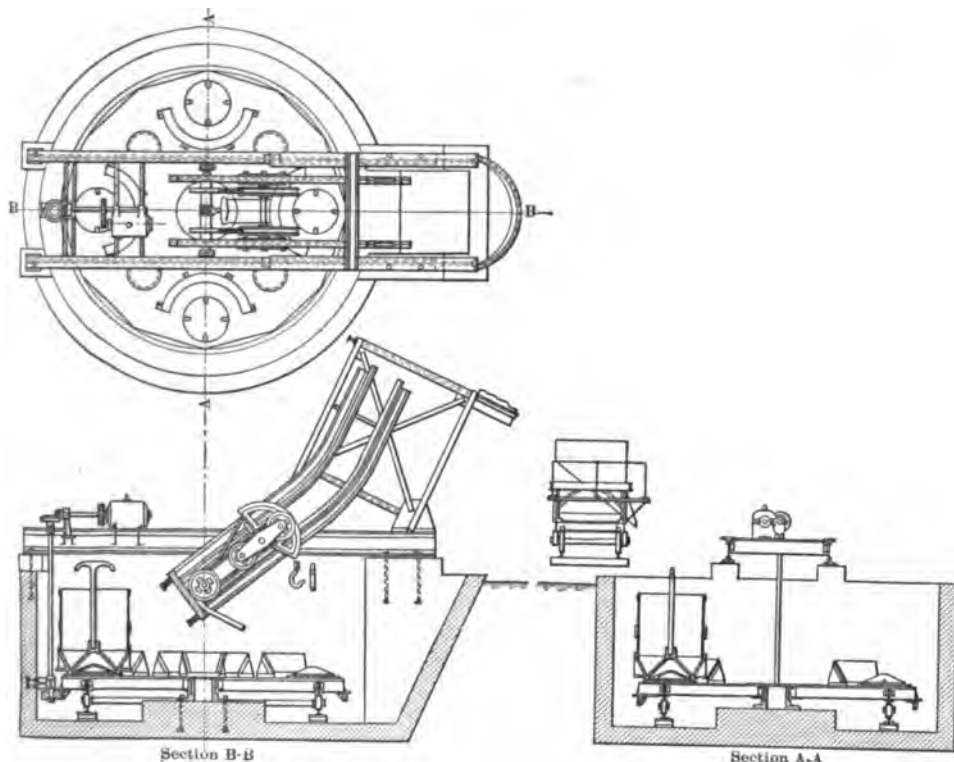


Fig. 50. Details of Neeland top, side elevation.

which acts as a guide for the rear pair of wheels. The upper portion of this guide is a circle struck from the center of the truck in its top position, and this circle permits the rear wheels of the truck to rise while holding the pivot of the quadrant rigidly in its place, and gives the required vertical movement to the bucket as a whole. This seats the bucket on top of the gas seal exactly as is done with the Duquesne top, but without the assistance of the vertical slide, and therefore somewhat more simply. The return of the rear wheels to their normal position is secured by a heavy counterweight which the rear wheels pick up just before they enter the guide, and which pulls them back down on to the incline as soon as the hoisting rope is slacked. The head-sheave is clearly shown just above the curved guide.

Other modifications of this type of top have been built, but the principle in any of them is no different from those illustrated.

At one of the most successful plants in the country the bucket is never unhooked from the carriage but rigidly attached to it just as the skip is attached to the hoisting rope, but provision is made for rotating the bucket on its vertical axis to each of three equally spaced directions in turn, this eliminates irregularities in charging it.



Figs. 51-53. Bottom of hoist, Ford-Parkes system.

It will be seen that this type of filling gives precisely the same type of distribution as the double-bell type of top, and with almost the same limitations. That is to say, irregularities due to the way in which the charge is delivered into the top may and generally do occur with either type of filling, and may be more or less completely compensated by the correct rotation of the receiving part to equally spaced dumping points in regular order.

At the same time it must be recognized that the advantage is with the bucket system if the top be not rotated because of the smaller number and lower velocity of transfers of the stock with corresponding reduction of the opportunity for segregation.

Guiding the bell movement.—One point of extreme practical

than on the other, and much bad furnace work has been attributable to this irregularity. The path of the bell rod must always be a straight line exactly in the center of the furnace. This straight line can be produced either by a rigid guide for the bell rod, connecting the latter to the lever with a short link; a quadrant from which a flexible suspension member unwraps always in a vertical line as the lever rises and falls, or a mechanical parallel motion similar to that of Watt's steam engine. A good illustration of the quadrant system is shown in Fig. 34, in which the bell is suspended from the triangles which are hung from chains working in grooves in the castings on the ends of the bell lever, these castings being segments of circles concentric with the center of the lever.

The parallel motion design is well shown by Fig. 36. The bell rod is not connected directly to the end of the main bell lever but to a short link which projects above it, the upper end of which is guided by a connecting link pivoted to a projection on the fulcrum of the main bell lever. The proportions are such that the bottom point of the suspension link where it is attached to the bell rod moves in an absolutely straight line. In Fig. 36 the small bell is guided by the main bell rod and therefore is not provided with any parallel motion, only with a suspension link to connect the curved movement of the bell lever with the straight-line movement of the bell rod. But in many cases the lever of the small bell is provided with its own parallel motion also. The rigid guide is used on the Baker top, the (two) bell rods passing through guide castings riveted to the gas seal and others on the superstructure at the upper end of the rods. The bell lever is connected to the rods by a short link as shown (not very clearly) by the drawing.

Bell-operating apparatus.—In the early days of the closed-top furnace the bell was probably always controlled by a hand-operated "crab," consisting of a crank and connecting rod driven by gearing. A large gear having a crank pin in its face was set immediately under the outer end of the bell beam and a connecting rod ran from a pin in the bell beam to the crank pin in the gear. When the pin was in its lower position the bell was shut, and the travel of the pin was such that when it was in the opposite position the bell was opened wide. A few of these crabs have remained in operation down to quite recent years, but they were superseded in general practice many years ago by a steam cylinder as shown in several of the preceding figures.

There are two methods of using the cylinder. One is to counterweight the bell so that it will stay shut even with the full charge upon it, and have the cylinder lift the counterweight to open it. This has the great advantage that if the steam connections are broken or any other mishap takes place, the bell remains closed and prevents the

entrance of air into the top of the furnace, which is necessary in order to prevent gas explosions.

In the other method of operating, the counterweight is dispensed with and the direct downward pull of the cylinder keeps the bell closed. This is somewhat simpler than the other method or at least permits doing away with the counterweight; moreover, by operating in this way the cylinder can be placed at or near the bottom of the furnace and connected with the bell by means of a wire rope, but obviously this cannot be done when the bell is kept shut by a counterweight. However, a counterweight can be applied at the bottom of the rope and immediately over the top of the cylinder if desired.

In some cases a compromise method is used and the bell is counterweighted about to the extent which will keep it shut when empty but not with the charge upon it. This requires less lift from the cylinder to open than the full counterweight method, and also requires less pull from the cylinder to close than the non-counterweight method. Of course the cylinder is made double acting in this case, which it need not necessarily be in the other cases, although it usually is. By this compromise method, and by equalizing the work on the up and down strokes of the cylinder, the latter can be made considerably smaller than when it is virtually or actually single acting.

The cylinder is an extremely simple method of operating the bell, but is not a particularly satisfactory one. It is obvious that the bell must be held to its seat against the hopper with sufficient pressure to make a gas-tight joint even when loaded with the charge, which probably averages between fifteen and thirty thousand pounds. The amount of actual work involved in opening and closing the bell is very small, but when a cylinder is used for this service, it must be large enough to hold the bell shut or to push it open under the worst conditions which can arise, and the cylinder must, therefore, be much too large for the work it actually has to do most of the time. This is apt to result in violent movement of the bell, unless the cylinder is steadied by a large dash-pot, and in totally unnecessary stresses on the bell beam and its connections. For this reason it is desirable to use some mechanism which has sufficient power to hold the bell tight shut in its closed position without the expenditure of unnecessary energy in moving it. Any mechanism which maintains control over the bell during dumping and closing, so as to prevent excessive velocity is sufficient.

It is very desirable to have a relatively slow movement of the bell at opening and closing so as to prevent slamming and violent inertia shocks on the whole mechanism. For this purpose the bell cylinders are piped as shown in Fig. 43. Inlet takes place through the pipe next the end of the cylinder, but discharge can only take place freely through the one further in from the end, since the outer one contains

a check which prevents return flow at any but a very slow rate, so that when the piston overruns the outer port it is cushioned by the steam trapped between itself and the head of the cylinder, and its velocity is thus checked at a rate slow enough to do no harm.

The cylinders generally require to be operated by steam, as compressed air for such purposes is expensive and is likely to be frozen up in winter. When the bell cylinder is placed at the top of the furnace great care must be used to prevent the pipes leading to it from being frozen, since there is no flow except when the bell is operated, and in severe weather during a relatively short suspension of filling an interval sufficient to permit freezing may occur between piston movements.

It will be seen that the crank and connecting rod has an absolutely smooth acceleration and retardation and that in the closed position it acts like an inverted toggle and holds the bell tight shut without expending any energy on it, so that it furnishes the ideal movement for this purpose. To make use of this ideal motion and to dispense with the necessity of steam or compressed air for operating bell cylinders an apparatus has been brought out in recent years which returns to the crank and connecting rod principle; but instead of being hand-operated, as the earlier ones were, it is driven by an electrical motor controlled by automatic switches. The design brought out by the Otis Elevator Company is shown in Fig. 55. Fig. 56 on a smaller scale shows more plainly the arrangement of the crank in relation to the gear. The motor drives worm gears enclosed in the housing shown, and these in turn drive an internal pinion which meshes with the teeth of the annular gear. Automatic switches practically identical with those illustrated in connection with the furnace hoists control the movement of the apparatus. When the starting switch is closed the motor starts and runs until it has driven the main gear and the crank through a complete revolution, when it is automatically slowed down and stopped. This obviously opens the bell and closes it again. The only objection to this apparatus is its very considerable cost, and the necessity of having such an amount of machinery at the top of the furnace.

It may be said that while the cylinder has its disadvantages for operating bells, with certain modifications it could be made to do very much better than the direct-acting cylinder, and in many ways almost equal to the expensive electrically operated apparatus without costing nearly so much.

The operation of gas-seal bells is practically the same as that of large ones, although it requires very much smaller apparatus, since the loads to be carried are much smaller and the small bell itself also weighs many hundred pounds less than the large one. In some cases

now the upper bell is operated by an electrical bell hoist similar to but smaller than the one illustrated, for of course it is desirable to have both operated by the same type of mechanism, to have either both steam or both electric.

The upper or gas-seal bells have generally been operated by cylinders working through levers the same as those used on the main bell, but several years ago Julian Kennedy of Pittsburg brought out a



Fig. 55. Electric double screw internal geared bell hoist, direct current.

design in which the cylinder for the small bell was placed immediately over it in the center of the furnace in an inverted position, its piston rod becoming the rod of the small bell. This, of course, dispenses entirely with the lever for transmitting the motion, etc., but is open to the objection that steam must be on the cylinder practically all the time in order to keep the bell shut, or else a counterweight and lever must be used.

This design is followed with the rifle-bar cylinder of the Baker top as already noted, but in that case the normal position of the small bell is open, so the cylinder is only under steam when the bell is being raised to close and rotate it.

Provisions for access and repairs — Means for hoisting main bell. — In the days when furnaces were hand-filled and practically the only mechanism on the top was the single bell with its lever and bell cylinder, considerations of accessibility played no part, there being but little apparatus and that all in plain sight. When a bell had to be taken down from the top of the furnace or sent up it was hoisted out with some simple but powerful hoist; set on rails and skidded over to the platform of the hoist, commonly known as the cage, on which it was lowered to the bottom and a new one to replace it was brought up in the same way.



Fig. 56. Bell hoist — crank end view.

With the mechanical top all that is changed. There is in all cases a considerable quantity of machinery and in many designs a vast amount. This is erected when the furnace is built and is never expected to be removed until the furnace itself is torn down. The main bell is not only at the bottom of a hopper in many cases deeper than the height of a man, but is covered over by an air-tight gas seal so that access to it is most difficult even for inspection, while before any repairs can be made a considerable portion of the top must be dismantled.

This is a point which has been too little considered in the design of furnace tops. Some engineer in a cool and pleasant drafting room designs some form of apparatus which pleases his fancy, and which may then be built easily enough because its construction is fundamentally no different from that of any other mechanical apparatus. But when the repairs become necessary they are turned over to the operating man, and must be made under circumstances which may be conservatively described as follows:

The temperature of every part that needs to be handled is high enough to burn the hand, in many cases so hot that the radiation makes it disagreeable to approach. Every crack and cranny is filtered full of dust that at the best is packed tight, and if it has been rained on is cemented almost as hard as iron. The air is not only heated almost to the point of suffocation in many cases, but in practically every case is mixed with furnace gas containing 25 per cent. carbon-monoxide, of which 1 per cent. in the atmosphere is quickly fatal, and a small fraction of a per cent. causes violent sickness. The nut of every

bolt is either burned or rusted fast, or so jammed with dust that it will move but one "flat" at a time, and often will not start at all except with a sledge hammer and chisel. The room available on the top platform is generally just sufficient to permit bare access around the top of the furnace when everything is in place. The little space in which one might move with safety or speed is seized for the storage of parts as soon as the top is dismantled for access to the bell and hopper.

Under these circumstances it would seem as though some consideration might be given to accessibility and to designing some of the parts, notably the gas seal, so that they would go to place and function properly without the necessity of coming to an exact position. It is almost impossible to bring these parts to exact positions after they have been subjected to the heat which is unavoidable and the flame which often occurs at the top of the furnace, but these points appear to have been given very little consideration by designers.

In quite a number of types the gas-seal hood which rests on the lip of the main hopper supports the distributor; this means that in order to change bells the whole distributor must be taken off and the gas seal completely dismantled before the real work of removing the bell can be started.

It will perhaps illustrate the operating man's point of view to explain the former method of holding the lip ring down to its seat in the hopper. This was almost universally done with square bars resting against the lip ring at the bottom and passing through a socket near the top of the hopper, a key in a key-way through the bar just below the socket was driven by a sledge so as to force the bar down against the upper edge of the lip ring, thus holding it to place. It is obvious that when the lip ring became loosened by the constant jar of the bell in closing, these keys could only be tightened by putting a man into the gas seal through a manhole such, for instance, as that shown in Fig. 36, and having him drive up the keys.

It will be seen that he had to stand in a V-shaped space without a particle of footing. The temperature under the seal in many furnaces is seldom much less than two hundred degrees, even if means have been taken to cool it off, while there is almost certain to be a certain amount of gas leakage through the main bell and no chance of obtaining adequate ventilation through the small manholes in the gas seal. I have known of at least one case where a man was killed by gas on going in under the gas seal to do some such work. The gas was not in sufficient quantity to be visible, and several men were rendered unconscious by it before the danger was realized, but by quick work on the part of the master mechanic, all were taken out alive except the one.

In course of time the operating men determined that the holding

bars for the lip ring must be tightened from outside the gas seal, and changed the construction to permit this, a practice which is now almost universally followed. The general principle of the method by which it is done is shown on the left-hand side of the hopper in Fig. 42.

Handling the bells for repairs. — Of course, neither the hoisting apparatus for the skip nor that for the bucket system of filling affords any possibility of handling the bells, and therefore some other provision must always be made for letting down old bells and bringing up new ones. This is very generally in the form of a runway extending well out over the side of the furnace, as shown in Fig. 36. In this case the runway is the same as that which carries the adjustable receiving hopper. When a bell is to be handled the hopper is removed and the trolley shown at the extreme left-hand end of the runway is brought into action. This trolley runs far enough for the bell when hanging from it in its outmost position to clear the furnace entirely and to be brought up vertically; then when it is above the hand-rail the trolley is traversed over to the center of the furnace and the bell lowered into place. Sometimes a jib crane is used for this purpose, but in some cases within my experience these have been forced out of plumb by distortion of the furnace top and have been extremely hard to swing around, especially when under load. For this reason the runway with the traveler is much to be preferred.

Ordinary hoisting arrangements cannot be used on the trolley on account of the great height of lift involved, and it is well to provide not only a trolley with its sheave, but to have some means of doing the hoisting quickly and safely.

Bells are certain to give out at intervals, probably their life does not average much over a year, and to have a good top design and good arrangements for hoisting and a top accessible without too much dismantling means the difference between a shut down of twelve and one of forty-eight hours.

The stock line recorder. — One of the most important points in connection with the filling of the blast-furnace is to maintain the stock line at the proper height. With hand-filling this was frequently very difficult to do. The physical limitations of the apparatus, to say nothing of those of the men, were such that if the furnace once "got down," that is if the stock line settled to a lower level than it should by the melting of the stock column below, it was very difficult to catch up, as I have already explained. If the stock line settles to the level which the stock should reach after it has been in the furnace for say two hours, then obviously the stock charged while that condition prevails is deprived of two hours of the time of treatment it should receive. This is frequently more than enough to derange seriously the working of the furnace.

For this reason it is of great importance that the furnace shall not only receive in one twelve hours the complement of stock which it requires, but that this should be received at a uniform rate, and the stock line kept constantly within a very few feet of its proper position. When the furnace is filled with skips their capacity for handling materials is so vast that there is not often any physical obstacle to prevent the furnace from being kept full, but the very speed with which it may be charged may be a disadvantage, since the men on the night shift may take a "spell" of an hour or two, knowing that by hard work they can catch up by daylight, although the furnace may be "down" many feet and its working deranged thereby, when they begin to make up for the time lost.

Gauging rods working through the top of the furnace, generally through the hopper or a point just back of its upper edge, have been provided ever since the introduction of the closed top, and in recent years, since the introduction of skip-filling, arrangements have been made whereby the test rod is suspended from a rope which winds on a drum at the bottom of the furnace, and by operating this drum the furnace can be gauged without the necessity of going on top.

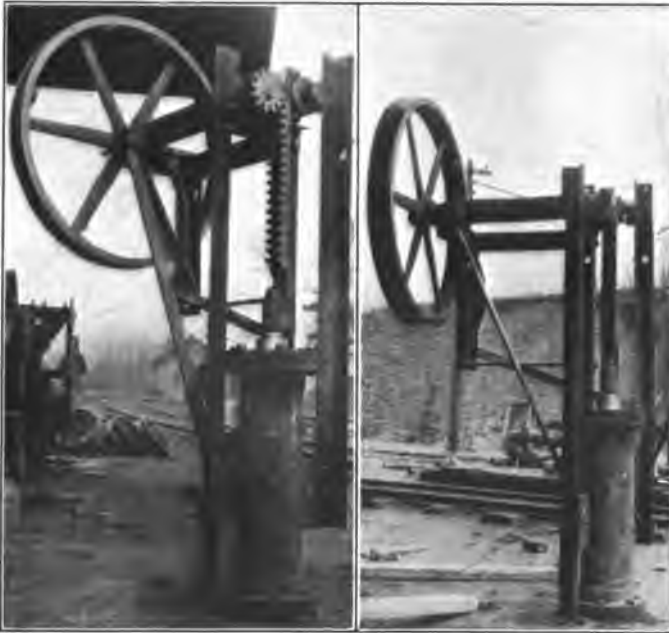
There is also another need to gauge the stock line. This results from the fact that while the stock line ordinarily settles quite regularly, so many inches per minute, at times the furnace slips and the stock line drops from two or three feet up to fifteen or twenty in moderate slips, and of course much greater depths in violent explosions. Even though the furnace be working normally below, it is highly desirable to have a record of the way the stock line is settling, so that any tendency to lag or work irregularly can be detected and cured without delay.

For the accomplishment of this purpose I designed several years ago an apparatus called a "Stock Line Recorder," of which the principle is very simple. (See *Transact. Amer. Inst. Min. Eng.*, Vol. XXXVI.) The test rod instead of being raised up out of action except when the furnace is to be gauged, rests normally on the stock and settles with it. When the bell opens to admit the charge the test rod is drawn up out of the way, and when the bell closes it settles back on the stock in its new position, and follows it down until lifted for the next charge, and so on.

The mechanism by which this is accomplished is extremely simple, the actuating portion of it is shown by Figs. 57, 58, 59. The test rod, which is made quite heavy, hangs in the furnace in the ordinary way. A light, flexible wire rope is passed over a sheave on top of the furnace, and from thence to any convenient point, preferably near the skip operator's platform, where the actuating mechanism is placed.

The rope is wound on the narrow flanged drum, shown at the top in the plan view. This drum is keyed to a shaft, on the other end

of which is keyed a small pinion meshing with a rack fastened to the piston rod of the cylinder shown below. The piston rod works through a metal gland with a fairly free fit so as to avoid friction. The piston is made quite heavy or else weight is added to it in some way so that this weight acting through the pinion and drum tends to take up the slack from the test-rod rope, but on account of the much greater radius of action of the rope, and the considerable weight of the test rod, the weight of the piston alone cannot lift it. The top of the cyl-



Figs. 57-58. Operating mechanism for stock-line recorder.

inder is connected to the main bell cylinder, generally without any valves or connections of any kind, so that when steam is turned on the main bell cylinder to open the bell, it is simultaneously turned into the top of the recorder cylinder, and forces the piston down, raising the test rod to its highest or "safe" position.

When the steam is exhausted from the bell cylinder to close the bell, it is simultaneously exhausted from the recorder cylinder, and the weight of the test rod with its greater leverage then lifts the piston in the cylinder until the test rod rests upon the stock, when it comes to rest, and only moves thereafter as the test rod settles in following the stock down. The movement of the mechanism is reduced by the lever shown in the back view (Fig. 58) and transmitted to the mechanical

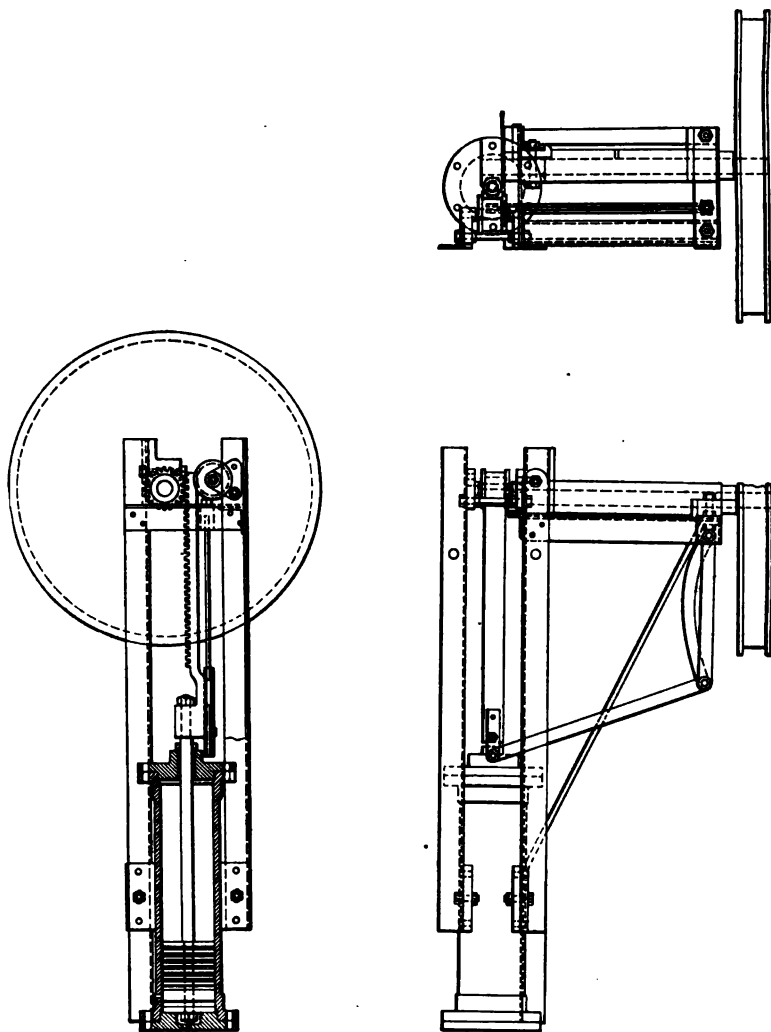


Fig. 59. Operating mechanism for stock-line recorder.

recorder, either of the dial or the strip type, and makes thereon a saw-toothed record as shown in Fig. 60.

The amount of information obtainable as to the way the furnace is settling, whether steadily or by slips, is quite remarkable. One accustomed to the type of chart produced by a given furnace can tell by a glance at it whether the furnace is working normally or not, while the check on the fillers, on the human side, is an absolute one since it must work if the furnace is filled, and in a number of years' experience no method was ever found by which the machine could successfully be "beaten."

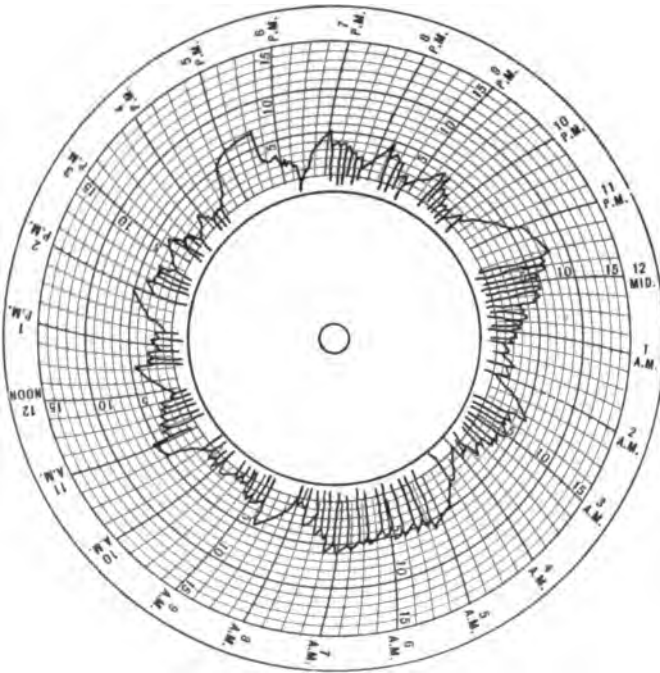


Fig. 60. Chart of stock-line recorder.

The subject of distribution is so vast, the number of variables and their reactions upon one another being practically infinite, and our knowledge of what the furnace really requires is so exceedingly limited, that the little we know on the subject has only been developed by an utterly disproportionate amount of trial and experimentation, both with models and with furnaces, and by the slow process of elimination of the most unfit. It is probable that a book could be written upon the subject if one were willing to go back and compile the results of the experience of furnacemen of the older generations.

But the question whether we will or will not use mechanical fill-

ing for furnaces has been settled for us, as have so many other questions, not upon the technical ground of whether its distribution is better than that of the hand-filled furnace, or the technical results better or worse than that of its predecessor, but by the stern law of necessity. The waning supply of men available for continuous heavy work, and the increasing wages which they command, combined with the absolute necessity of continuous operation irrespective of all other considerations, have forced us to adopt mechanical filling. There is no reason to believe that circumstances will ever alter so that large plants will be able to go back to hand-filling, even if they should so desire.

It remains, therefore, only for us to use our best endeavors to find out the fundamental laws of distribution, and then to design an apparatus which will conform with those laws and survive under the conditions on the top of the furnace. These are that any apparatus placed there shall receive a scant inspection surely not oftener than once a shift; that a shut down for its repair or for overhauling will be tolerated certainly not oftener than once in six months; that it must operate twenty-four hours a day, and seven days a week; that it must practically always be almost at the limit of working temperature for ordinary machinery; that it must be not infrequently exposed to a much higher temperature and often to flame itself, and that it must work in an atmosphere composed largely of the dust of one of the most abrasive materials in the world. That, further, it shall receive its material with irregularities depending upon a thousand circumstances, and shall smooth these out and deliver the material properly to its place on the main bell. That it shall pass pieces of scrap iron up to several hundred pounds in weight, two or three feet in length, and of almost inconceivable roughness, without injury to itself, and without delay, and that finally the total height through which the material must pass in the performance of these operations shall be a minimum, so that the coke shall be broken up as little as possible.

If in the scant twenty years which have elapsed since the mechanical top became widely introduced we have not achieved perfection in all these results, it is perhaps nothing to cause surprise. In contemplating the long distance we have come from the vast amount of expensive labor, the derangements of the furnace due to frequent inability to keep it full and from the horrible results of the early attempts at mechanical filling, I think we have every reason to feel, if not satisfied, at least that we have made great headway, in one of the most difficult tasks of designing ever submitted to the engineer and metallurgist.

CHAPTER III

THE BOILER PLANT

IN the early days of blast-furnaces when furnaces were small and the quantity of iron made per cubic foot of furnace capacity was very small as compared with present practice, the quantity of power required to drive the furnace was relatively insignificant. In that early day the gases from the top of the furnace were allowed to burn to waste in the air, and plants were generally located with reference to a water-power site.

With increase in size and rate of driving, the amount of power required increased very rapidly. We shall see in a later chapter that this increases nearly as the square of the output of a given furnace, and that modern furnaces require from 2000 to 3000 horsepower to drive them. Consequently as furnaces were driven harder it became more and more difficult to find water powers adequate to blow them. This, with the increasing introduction of the steam engine in suitable sizes and designs, and the increasing realization of the vast fuel value of the furnace gases, led to the introduction of steam power for blowing furnaces.

This step was hastened by the advent of anthracite as a furnace fuel, the pressures required with it being so much greater than they are with charcoal fuel in a given size furnace, and under conditions similar in other respects.

The question of the quantity of furnace gas per ton of iron produced and its heating value will be treated at some length in a later chapter, but in tracing the development of the present subject we may say that in ordinary, good modern practice about one-half of the total thermal value of the fuel charged comes out of the top of the furnace in the form of its top gases. Some 6 to 10 per cent. of this heat is in the sensible condition, the rest is contained in the gas in the shape of CO, whose combustion with air gives 4370 B.t.u. per pound of CO, or 10,200 B.t.u. per pound of carbon contained.

In good modern practice there are produced per ton of iron on the average about 140,000 to 200,000 cu. ft. of gas, of which about 60 per cent. by volume is nitrogen, and the remaining 40 per cent. is made up of CO, CO₂ and hydrogen in varying quantities; this gas has a thermal value ranging from 90 to 115 B.t.u. per cubic foot.

In Lake ore practice the quantity produced is from 140,000 to

160,000 cu. ft. per ton of iron; the analysis approximates N 60%, CO₂ 15%, CO 23%, H₂ 2%, and the heating value 95 B.t.u. per cubic foot.

In districts where leaner ores are used and correspondingly more coke is required the percentage of nitrogen does not alter much, but the CO increases at the expense of the CO₂ with proportional enrichment of the gas and increase in its thermal value.

In the early furnaces, this gas was allowed to escape freely from the top of the furnace, from which it burned continuously in a great flame, visible at night for miles; this is the case at a few cold-blast charcoal furnaces to this day.

The first attempts to utilize the heat of the waste gases were directed toward heating the blast rather than to generating steam. Furnaces were quite commonly built, 30 or 40 years ago, with a small pipe stove, of the general type to be described later, on top of the furnace and immediately over the throat, the gas rising from the latter mixed with the air and the resulting flame was drawn up through the stove. One or two charcoal furnaces built on this plan are still in operation now (1916). This construction, at least in some cases, necessitated the filling of the furnace entirely on one side and wonder is that furnaces could operate at all under this handicap, in fact, it is perhaps the greatest tribute to the hot blast that a furnace with hot blast produced in this way would do enough better than a cold-blast furnace symmetrically filled to make the change a profitable one.

The next development in the utilization of the furnace gas was to put both boilers and stoves on a masonry structure as high as the top of the furnace, and lead the gas off through flues opening into the stack several feet below its top. The resistance of the stock column above the flues and the draft of a powerful draft stack at the far end of the system served to draw the gas off through these flues. Air drawn in from the top of the furnace through the inversities in the stock mixed with the gas so that it was drawn through the stoves and boilers, not as gas but as flame.

The idea that the gas kept from contact with the air could be led about and burnt at practically any desired distance from the top of the furnace seems to have been rather slow in taking hold. The introduction of the bell and hopper enabled the top of the furnace to be sealed tight except when the bell was opened to charge the stock, ordinarily only about 5 per cent. of the time. Finally the gas lost during this interval was saved by the introduction of the upper bell. Under these conditions the top of the furnace is never opened to the air and a constant pressure is maintained sufficient to force the gas through the downcomer and mains to the boilers and stoves, or to the cleaning system, as the case may be.

In this system, therefore, the mains carry not flame but gas, which may even be reduced to atmospheric temperature and still remain an excellent combustible.

Under these conditions the gas can be led without difficulty to very considerable distances and consequently the stoves and boilers can be located with reference to other considerations. They have accordingly, for many years past, been placed on the ground and in positions best suiting the convenience of the plant as a whole.

This gas containing, as has been said, roughly 50 per cent. of the total energy of the fuel charged, supplies the heat necessary for all the operations around the plant outside the furnace itself. Its first and foremost use is for the purpose of heating the air, with which we have no present concern. This, in good practice, consumes about 25 per cent. of the total gas. In first-class modern practice another 12 to 16 per cent. is required for blowing power, and 5 to 10 per cent. for miscellaneous purposes around the furnace, hoisting, pumping water, etc., and loss, leaving about 50 per cent. of the gas, or nearly 25 per cent. of the total energy of the fuel charged, available for purposes entirely independent of the furnace.

The steam plant at the blast-furnace has been until very recent years a poor and inefficient one, measured by the standards prevailing at similar periods in other lines of industry. The reason for this is not far to seek. When the closed-top furnace was introduced, and it was found that the gas could be forced by this means to any desired point within reason, it soon developed that the furnace possessed a source of power ample for its needs, even with the cheapest and simplest type of steam plant.

Steel mills at that early day were not generally built immediately in conjunction with furnace plants as they are to-day, and the latter, therefore, did not generally have any local market for the surplus power, and until the general introduction of electricity for lighting and power transmission there was no disposition for power except such as could be developed immediately where it was to be consumed. Hence there was no use for surplus power which might be developed by the use of economical machinery, and as this machinery was higher in first cost, and more expensive to operate than the simplest and plainest type, the latter was in almost universal use until within the last fifteen or twenty years. Slide-valve or piston-valve engines with late cut-off and little expansion, using low boiler pressure, and running non-condensing were the rule.

The boilers likewise were of the cheapest, simplest and generally most inefficient types. Plain cylinder boilers with their enormous settings and proportionately excessive air leakage were the prevailing style until within the last twenty or thirty years. These boilers were literally plain cylinders, or sometimes a pair set side by side, from 3

to 4 feet in diameter and 40 to 50 feet long, entirely without flues. Sometimes there were two pairs, one above the other, the lower one joined to the one vertically above it by necks on each outside or "high" sheet, the whole suspended from two or three suspension points and exposed to the flame up to a height just below the water level in the upper cylinder, the gases making only one pass straight through to the chimney connection.

On account of their enormous water contents in comparison with their heating surface, these boilers possessed a great quantity of reserve energy, and steam pressure would not drop injuriously during a few minutes' suspension of the gas supply. They were also very easy to clean because containing no tubes. Men could be put inside them and chip off the scale with chisels or brick axes, which, of course, is impossible in other types of boilers except as to a small fraction of their heating surface.

Other than this these old types of boilers had little to recommend them, as the great cost of the setting and the high price per square foot of their heating surface made their cost per horsepower installed about as high as that of better types.

The great increase in the tonnage of iron produced in a furnace of a given size, which might almost be said to have culminated with the Duquesne revolution, and the increase in the size of the furnaces themselves, both acted in the same direction, that of requiring a higher blast-pressure to force the desired quantity of blast into the furnace. This in turn required more power, and therefore the practice which had been adequate if not ample for the old conditions became inadequate for the new, because its consumption of steam was so great that the combustion of all the furnace gas available was frequently unable to supply the quantity required. When this occurred it was necessary to burn coal under the boilers, and such coal represented a dead loss.

During the same period the integration of iron and steel plants developed extensively. Furnaces were built at large steel plants, or steel plants at furnaces in order that direct metal from the furnace might be used at the steel plant with a great saving in expense for both, the furnace sending the iron in ladles to the steel plant and so avoiding the cost of casting and handling it, while the steel plant avoids the greater cost of remelting it.

The well-equipped furnace plant having generally, if not always, a considerable excess of steam at its command, advantage was taken of this fact by running a steam pipe from the furnace boilers to the steam mains at the steel mill, the latter using enormous quantities of power, but having no source of supply of its own except by burning coal or other commercial fuel.

The great value of the power so supplied became more and more appreciated and the power plant at the blast-furnace was gradually improved so as to leave a larger margin of gas available for the steel mill, and this process has now gone on until some of the finest and most economical power plants in the world are those employed in blowing blast-furnaces, while the subject of power development for this purpose has enlisted the closest attention in Europe and more recently in this country as well.

It is a rather interesting fact that this gradual progress from the utter indifference which came from having a prodigal supply of power and no use for the surplus, to the present condition in which the expenditure of every thermal unit is watched with a jealous eye, lagged a little behind the development of the steam boiler from the relatively crude types, which I have described, and which were in practically universal use at one time in all other industries as well as at the blast-furnace, into the modern water-tube types. In other industries after the single-flue and two-flue boilers, came a gradual increase in the number and decrease in the size of the flues, the multitubular boiler, which was for so many years the standard in good steam practice. Then came the later evolution, forced by rising steam pressures, from the horizontal tabular boiler to the water-tube boiler, which became well established about the time the demand developed for more economical boilers for blast-furnaces.

In this way blast-furnaces skipped that period of development during which the horizontal tubular reigned supreme in most industries, and passed immediately from the cruder types to the modern water-tube boiler.

Horizontal tubular boilers. — At the Illinois Steel Works in South Chicago, where coal was expensive as compared with Pittsburgh, and where a furnace plant and steel mill were early operated in conjunction, they used at one time a great number of horizontal tubular boilers; but this is the only large blast-furnace plant, to my knowledge, where extensive use was ever made of this type of boiler. These have now all been superseded by water-tube boilers.

In New England, where fuel is expensive and where the textile mills use in the aggregate almost as much power as do the steel mills of the country, so that their operators have been forced to use every possible economy in steam generation and utilization, they continue to use the horizontal tubular boiler to a great extent, even down to the present time.

It is, therefore, not on the ground of economy that this boiler has been driven out, but rather by two demands of modern practice which jointly have set conditions impossible for it to meet. These two conditions are, first, increasing steam pressure; second, a demand for large

individual units so as to keep down as low as possible the total number of units for large powers. Both these conditions necessitate heavier shells for horizontal tubular boilers, and since these are exposed to the direct action of the fire their safe thickness is limited to that which will permit the cooling effect on the inside to prevent the rapid burning or cutting away of the outside, particularly at the seam with its double thickness and projecting rivets.

Water cooling is effective against the direct action of fire only within certain definite limits of thickness, and these are approximately reached in the horizontal tubular boiler at a capacity of 300 horsepower and a pressure of 125 lb. to the square inch, and though by special construction these conditions have been exceeded in horizontal tubular boilers, this pressure is lower than that demanded by modern practice, and the units are smaller than is desirable in large plants. Hence the horizontal tubular boiler is eliminated from the competition.

Moreover, the question of safety is always to be considered, and while it must by no means be thought that water-tube boilers are free from accidents, it must be admitted that the consequences of such accidents are probably on the average less destructive to life and property than those of horizontal tubular boilers.

The number of types of water-tube boilers which have been introduced in the last twenty or thirty years is literally legion. Many, if not most of them, have been applied from time to time and from place to place, in blast-furnace service. Many of them are still in such service. But the development of modern plants has settled down to the use of half a dozen types, of which we may consider four.

Before proceeding to a description of these, however, a general review of the conditions of operation of boilers at blast-furnace plants will not be amiss. These differ in some respects from those prevailing in ordinary installations. First, they are normally gas-fired, though provision is always made for the use of coal should it become necessary. Second, the furnace gas with which they are fired generally contains a considerable quantity of dust which settles on the tubes and heating surfaces and, if not removed, rapidly impairs their conducting power. Third, the boilers are operated twenty-four hours a day and seven days a week. There is no stoppage of the plant over Sunday during which the boilers can be cleaned, as is customary in other industries, and for this reason a sufficient reserve of boiler power must be installed to allow at least one unit to be constantly out of service for cleaning. Other than these, the conditions do not differ materially from those of economical boiler operation in general.

General considerations concerning water-tube boilers. — The first and most important condition is, of course, that the tubes must be kept clean, not only externally but internally, and until very recent

years it was practically impossible to do this in any except perfectly straight tubes. This is no longer true, but at the same time straight tubes are greatly to be preferred to curved ones, as they are less expensive and generally far less troublesome to replace than curved tubes, and in everything except length are interchangeable, which cannot be the case when curved tubes are used.

Owing to the nature of hydrostatic pressure, any vessel subject to such pressure tends to become circular, and if any other form than this be used, in order to resist deformation it must be given greater strength than would be required by the circular form in a proportion greater than its deviation from the latter. For this reason flat, parallel surfaces on upper and lower drums, until recently the only ones between which straight tubes could pass, have been frowned upon by boiler insurance companies and boiler inspectors, particularly during recent years when pressures have risen far beyond what they were ten years ago, because of the difficulty of staying such flat surfaces so that they will stay flat, and the liability to excessive stresses and leakage, and even failure if they distort under pressure.

Moreover, it was for a long time very desirable to have the tubes not only straight, but to have them so set that their ends could be exposed and a cleaner, carried by a rigid rod a little longer than the tube, inserted and driven through. This could not be done if the tubes were set in drums, because the drum would prevent the insertion of a cleaner so mounted into the tube. Therefore, two of the most



Fig. 61. The Heine Boiler without its setting.

successful of the earlier types of boilers had parallel water legs depending from opposite ends of a combined steam and water drum above, and from one of these water legs to the other ran the straight tubes. The water legs could obviously not be circular in shape and yet permit the use of straight tubes, so they were made in various ways to give the necessary strength and access to the tube ends, and at the same time permit the use of straight tubes.

The Heine Boiler.—One of the types of boilers on this general plan is the “Heine,” built by the Heine Safety Boiler Company, and illustrated in Figs. 61 and 62. Fig. 61 shows the construction of the boiler independent of its setting. The water legs are made of flat plates

stayed together by screw stays, as in locomotive-boiler construction, the perfectly flat parallel surfaces lending themselves to safe and adequate staying better than any other shape. The inner surfaces of the water legs act as the tube sheets, while holes a trifle larger than the tubes and exactly in line with them are cut through the outer surface of the water legs. These outer holes are closed when the boiler is in operation with a hand-hole plate, dog and bolt, but when the tubes are to be cleaned or removed these hand-hole plates are removed and give free access to the ends of the tubes.



Fig. 62. The Heine boiler in its setting.

The screw stays should be called stay tubes and not stay bolts, because there is a hole through each of them large enough to permit the entrance of a half-inch pipe with a steam jet on the end, and as these stay-tubes are in the center of the space between the water tubes this permits the steam jet to pass down between the latter from end to end, and thus effectively to blow the dust off one-fourth of each of the four surrounding the space.

This is necessary with boilers in all industries, but is particularly necessary at blast-furnaces because of the great quantity of fine dust carried by the gas at the majority of plants.

The boiler in its setting is shown in Fig. 62, which also shows the baffling. It will be seen that the gases go to the rear, then to the front, and then to the rear again, passing around the drum on their way to the stack. For this reason the drum is covered with fire brick above the water line, and this is very important because I have seen the drums of this type of boiler badly burnt through failure to keep these covering bricks in place.

Fig. 62 shows a boiler adapted only for the burning of coal, but only two minor changes are required to adapt it to burning furnace gas also. First, it should be set a little higher above the grate, and a burner opening should be provided through the front wall between the bottom of the water leg and the top of the fire arch. Second, the tiles used as baffling immediately over the fire should be of the type which completely surrounds the tubes, covering their lower as well as



Fig. 63. Wrought steel inclined header. B. & W. Boiler.

their upper surface, as such tiling constitutes a water-cooled fire arch. The tiles become hot enough to help combustion, whereas the relatively cold tubes kill down the flame before the gas and air have a chance to mix sufficiently to produce complete combustion. When such gas has once been extinguished it will not reignite, but passes out of the stack unburnt and represents a dead loss.

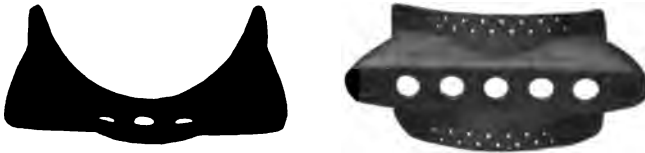


Fig. 64. Forges steel cross box.

The Babcock & Wilcox boiler. — This boiler differs from the Heine principally in having the water leg subdivided into as many sections as there are vertical rows of tubes, this being a still further extension of the sectional idea for localizing and minimizing the effect of failure of any part. As the arrangement of the tubes in a vertical plane is staggered, these headers are made sinuous, as shown in Fig. 63.

A saddle or cross-box shown by Fig. 64, is riveted to the drum, and each of the headers is connected to this by means of a straight tube expanded into the top of the header at one end and into the bottom of the cross-box at the other.

The boiler as a whole is well shown by Fig. 65. This boiler is suspended from a structural steel frame instead of being supported directly on the brick, as is the case in the Heine boiler. Another difference from the latter boiler is that in this case the passes are at right angles to the line of the tubes instead of parallel with them.

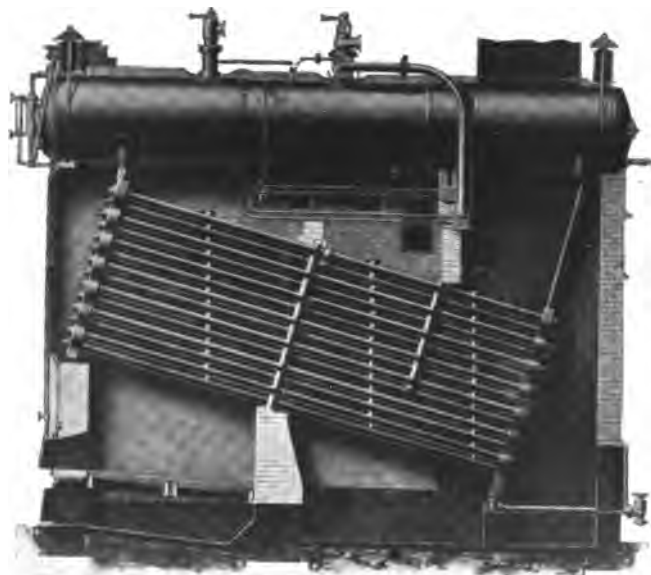


Fig. 65. Babcock & Wilcox boiler in setting.

The baffles are built up of fire brick supported by clamps around the tubes. These fire bricks make a continuous wall with the tubes passing through it, and supporting it. One of these walls run up from the lower bridge wall, the other comes down from the suspended upper bridge wall, the passage of the gases being first up, then down, and then up again, either out above, or through the suspension tubes of the rear headers, and into an underground flue.

The arrangement of having the gas pass off upward is very much to be preferred to that in which it passes downward because the latter involves the use of underground flues, and when these become obstructed by dust as they ordinarily do in the course of a few month's run, they can in general only be cleaned by shutting down the plant and putting men into them to shovel them out. In some cases the arrangement is such that a heavy stream of water can be turned into the flue and the dust washed out with this, but even this arrangement is inferior to the overhead flue, which may be provided with dust pockets through which the dust can be drawn into carts or wheelbar-

rows before it accumulates to an objectionable extent, and without any interruption to operation.

The boiler here shown is equipped with a super-heater, this being the U-shaped coil lying on its side in the space between the bottom of the drum and the top of the water tubes. Super-heaters have never been used in blast-furnace practice until recently, probably for the reason that they have the reputation of requiring a good deal of maintenance, and a correspondingly large number of interruptions to service, both of which would go far to offset any advantage they might produce in steam economy, interruptions to continuous service being particularly objectionable, but in modern plants super-heaters are being installed.

These boilers can be arranged for gas firing exactly as described for the Heine, by the introduction of a gas burner immediately above the fire door, but my preference is strongly in favor of the use of a combustion chamber for burning furnace gas, and as the tiles surrounding the tubes cannot be used in this boiler because they would cut off the passage of the gas and flame completely, I am strongly in favor of the use of a Dutch oven in front of these boilers when they are to be fired with furnace gas.

Such a Dutch oven will be described and illustrated in connection with the Rust boiler, and therefore need not be described in detail here. In order to apply it successfully the boiler generally requires to be set somewhat higher than when no Dutch oven is used, but this is a matter of slight first cost and no subsequent disadvantage.

The sinuous headers fit into each other very closely and no opportunity is permitted to introduce a steam jet longitudinally between the tubes. Consequently, in order to permit these boilers to be blown off, three sets of blow-off doors are provided whose location is indicated by the three vertical rows of white dots between the tubes in the illustration. The brickwork is cut away from these doors at an angle of 45 deg. on each side, and individual blow-off holes are provided opposite the space between each two rows of tubes. By this arrangement a steam jet can be inserted between each pair of horizontal rows, and also above the top one, and swung through a wide angle. By doing this from both sides the dust may be blown from the tubes quite effectively.

The headers are provided with holes in each side exactly like the water legs of the Heine boiler, the outside one being covered by a cap, held to place against the pressure of the steam with a bolt pulling against an inside dog. This puts the joint on the outside of the header, and these are all ground so that a metal-to-metal joint can be made.

These caps give access to the inside of the tubes for cleaning exactly as in the Heine boiler, and like it at the expense of two hand-hole

joints to make for each tube, to which some operators object on account of the pains necessary to keep these joints in good order, although if they are made thoroughly tight before the boiler starts up, they seldom give trouble in operation.

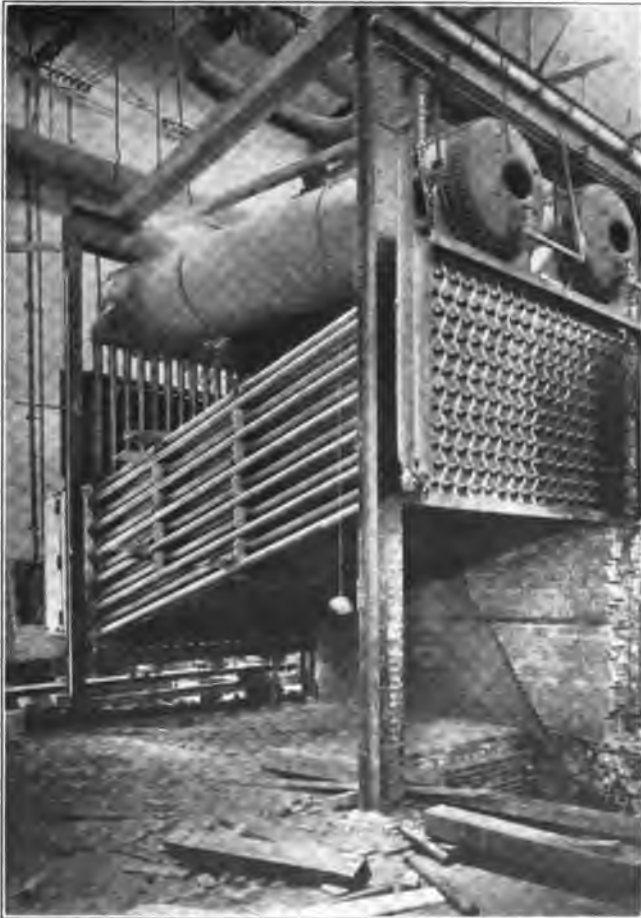


Fig. 66. Babcock & Wilcox boiler in course of erection showing how headers fit into one another.

The Stirling boiler. — This boiler and its setting are both clearly shown in Fig. 67. This boiler is of an entirely different type from both the two preceding ones in two important particulars. First, there are no headers but three circular drums above and one below. From each of these three a set of tubes run to the lower one. Second, as the tubes all enter the drums radially they are necessarily curved at the ends to a greater or less extent.

This construction eliminates the header altogether, but introduces the curved tube, and also cuts off access to the tube with a bar or cleaner of any type except a flexible one.

This for many years was the most serious obstacle to the continued successful operation of these boilers. They were furnished with scrapers mounted on chains with a weight on the end, this weight was

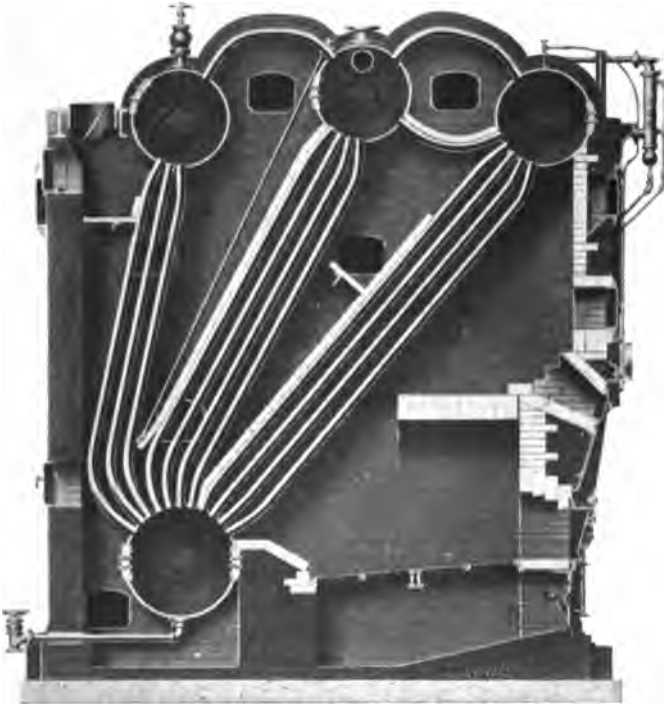


Fig. 67. Stirling boiler in setting.

dropped through each tube in turn and the scraper then pulled through after it. It will be seen that this was an exceedingly laborious operation, particularly as the drums are small, only 3 to 4 feet in diameter, and men could consequently only work lying down or crouched very low. The air in these drums is generally not of the best and the slightest leak of hot water from the steam connections above, or the blow-off below, makes them an almost intolerable place in which to do any work, especially the violent physical labor involved in hand-scraping.

These conditions have been very much changed by the introduction of power cleaners, which we will describe briefly at the end of this chapter.

The baffling in these boilers is inclined, following the line of the batteries of the tubes running to the different drums. The course of the

gases is up, down, and then up through the stack connection to the draft opening just back of the rear drum. Three ordinary cleaning doors are provided above and one below, through which a steam jet can be introduced into the setting and the dust blown from the tubes, but owing to the steep angle at which the latter stand dust has not ordinarily the same tendency to settle upon them that it does on tubes that are approximately horizontal.

The bottom drum serves as a mud drum, and the sediment concentrated by the evaporation of the water gathers there, at least in part, and is blown off through the blow-off valve.

The feed takes place in the rear upper drum, which is entirely filled with water, and from there the feed water passes forward to the second and finally to the forward drum, there being a set of water tubes below the water line, and also steam tubes above it, connecting the front and middle drums, which serve as steam drums, particularly the middle one.

The setting of this boiler is regularly provided with a partial combustion chamber, and therefore furnace gases may be burnt under it by introducing the burner immediately above the fire-door, but for best results with furnace gases the setting should be modified by throwing its lower part forward so that the combustion chamber is made longer.

As between the Stirling and the Babcock & Wilcox boiler some prefer the Babcock on account of its straight tubes and ease of cleaning, while others prefer the Stirling, claiming that it gives drier steam, and also because it does not have a multiplicity of hand-hole plates to put on, take off, and keep tight.

The Rust boiler. — This is the latest developed of any boiler in extensive modern use. It was invented to solve what had seemed for many years an insoluble problem, that of making a boiler containing nothing but straight tubes, and yet using only circular drums. This seemed impossible, because it is necessary for the tubes to enter the drum radially in all the older constructions, and this means that all the tubes except one row must be bent to reach this direction, as is clearly shown by the illustration of the Stirling boiler.

Mr. E. G. Rust, then chief engineer and later general superintendent of the Colorado Fuel & Iron Company, overcame this difficulty by making a forged steel tube sheet for the drum, which is circular in its principal section, but which has forged into it cup-like depressions whose axis is not radial to the drum, but in the line which the tubes are desired to have. This is shown by Fig. 68. These tube sheets are made of sufficiently heavy material so that even after the drawing necessary to form these pockets the material is amply strong.

The boiler in its setting is well shown by Fig. 69. It consists of

four drums, two below and two vertically above, connected by five rows of straight vertical tubes. A bridge wall extends up from the foundation between the two elements of the boiler. The flame comes in on one side, passes vertically up, surrounding one nest of tubes, over the bridge wall and down, surrounding the other, thence to the stack. The bottom drums are connected by a single row of straight tubes, the top drums by an upwardly curved set of tubes for steam, and a downwardly curved set for water, the latter carrying baffle tiles to keep flame out of contact with the drums above the water line.

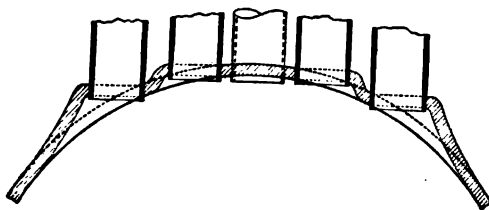


Fig. 68. Rust tube sheet.

One of the advantages claimed for this boiler is that the tubes being set vertically the dust has a minimum tendency to adhere to them, nevertheless three horizontal blow-off doors are provided which are of the same type as those described for the Babcock & Wilcox boiler, but set horizontally in this case so as to be at right angles to the line of the tubes. The setting of this boiler precludes the possibility of having the flame burn directly upward against the tubes, and owing to this construction a Dutch oven must be provided even with coal firing, which makes its adaptation to blast-furnace gas very easy.

Fig. 70 shows the front of a battery of these boilers equipped with gas burners above the fire doors. The gas main may be seen in the upper right-hand corner of the illustration, with its connections to the individual pairs of burners. The valves controlling the latter, operated by wheel and hand-chain, are also shown.

It seems no more than fair to say that these boilers are generally preferred above any other type by blast-furnace managers who have used them.

Gas burners for boilers. — Blast-furnace gas is a relatively lean gas. When of the normal composition given above it requires about 60 per cent. of its own volume of air for theoretically complete combustion, to which a small excess is generally added because while the losses from heavy excess of air are very great, those from unburnt combustible are still greater, and as it is impossible to maintain an absolute adjustment of air to gas it is better to err on the side of having a small excess of air rather than any considerable quantity of unburnt fuel.

In order to get the best results with the least excess of air an intimate mixture of gas and air must be made, and as the velocity of the gas through the boilers under the effect of draught is high the time

for making this mixture is limited to a small fraction of a second. For this reason the entering currents of gas and air must not only be in intimate contact, but must present a maximum surface of contact for the area of opening required. This result is obtained either by the use of multiple ports for gas with air ports between, or by the use of a narrow port for gas with air on both sides. The latter is the type shown in Fig. 70.

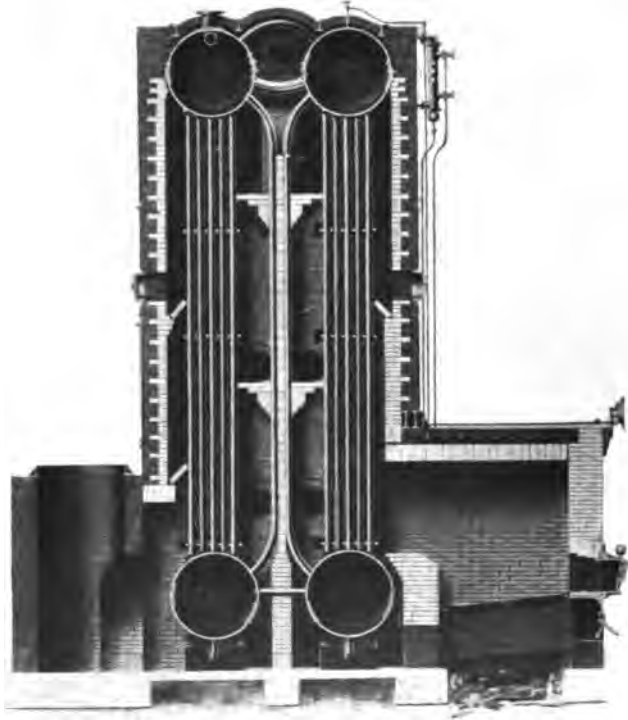


Fig. 69. Rust boiler in setting.

The end of the curved flat burner projects into the front of the fire box with a clear space for air all around it. By the simple expedient of having a rectangular frame surrounding the burner and sliding on it, which can be pushed up close to the fire box front or drawn away as desired, the amount of air admitted may be varied at will, while the amount of gas may be controlled by the gas valve above. This provides independent regulation of air and gas, admitted to be a prime necessity for the most economical combustion of furnace gas.

In former times gas flues from the furnace to the boilers generally ran underground, and in these cases the burners were arranged to

stand over an opening in the top of this flue. But such flues are unsatisfactory, both because of the difficulty of cleaning them out, which is even greater than in the case of the chimney flues, and because being under the ground their tightness can never be insured, nor the amount of leakage from them determined, and leakage of furnace gas is not to be tolerated because only a few cubic feet in a large room are sufficient to cause sickness and violent headaches, if not more serious con-

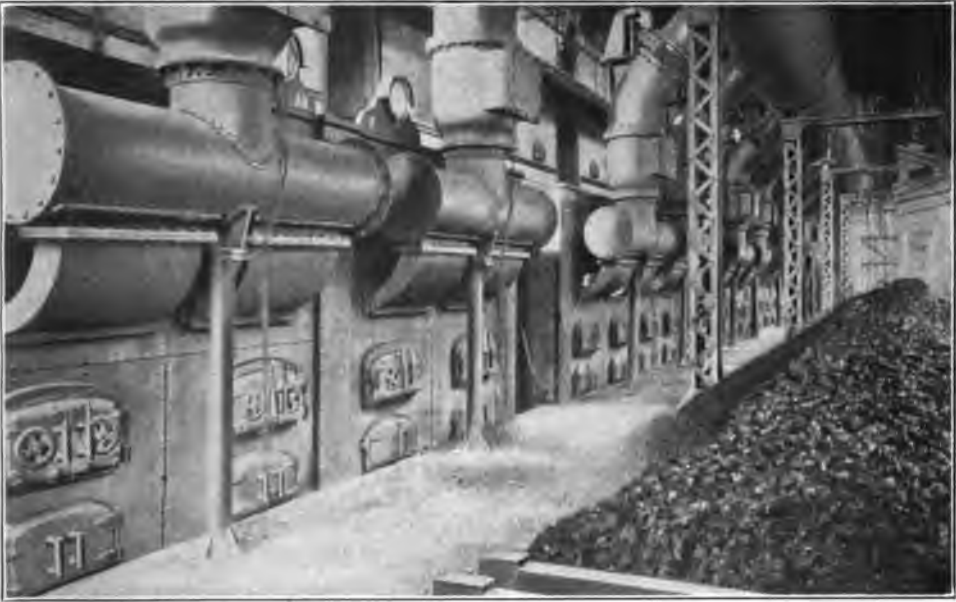


Fig. 70. Burners for blast furnace gas.

sequences. Therefore, overhead mains of steel lined with fire brick are now commonly used, and the burners are suspended from them in some such way as that illustrated. This is a decided advantage, not only for the reasons given but because the burner is completely above and out of the way of the fire doors in case coal firing is necessary. This is by no means the case with burners coming up from below, which are not infrequently in the way at such times.

Precautions as to grates. — When a Dutch oven or combustion chamber such as I have recommended is used, the radiation downward from its roof or top surface is intense, while the grates are not protected by a current of air up through them as they are when coal is burned, since the air must be admitted with the gas for reasons explained above, and therefore the ash-pit or draught doors must be kept closed.

For this reason the grates should be lightly covered with some sub-

stance such as coal, ashes, or even a layer of brick laid loosely over them, to cut off the heat from above, otherwise the radiation from the arch is liable to melt them down or at least fuse shut the air openings. This might not be observed so long as the gas supply continues, but if in an emergency it suddenly becomes desirable to fire coal, the grates being worthless, none can be burned, and serious delay results, as well as the loss of the grates.

Very frequently the grates are protected by having a bed of coal spread on them which burns very slowly because no air comes up through it; the hot upper surface of this serves to light the gas instantly if the supply should fail momentarily and then start again. This is a matter of much importance, because if a mixture of gas and air fills the setting before ignition, an explosion will result when ignition takes place, and the setting at least will be seriously damaged; even the boilers may be thrown out of place and they or their steam connections ruptured. Accidents of this kind have frequently occurred, and too many precautions cannot be taken to avoid them.

Boiler cleaning.— I have already described the earlier and cruder methods of cleaning water-tube boilers. It is not too much to say that these methods were so ineffective and the difficulty of keeping the tubes of these boilers in condition was so great that it seriously retarded the introduction of this type of boiler.

When scale becomes too heavily incrusting upon the tubes of a horizontal tubular boiler to be removed in any other way, the tubes can be cut off and removed bodily from the boiler, and the scale can then be cleaned off of them without much trouble or expense. The tubes can then be welded out to their original length and replaced in the boiler. This is not a matter of prohibitive expense. But when a water tube becomes heavily incrusting with scale it cannot be cleaned even in this way because the scale is as inaccessible when the tube is out of the boiler and when it is in place. This is so serious a consideration that the writer on one occasion needing additional boiler capacity installed a horizontal tubular boiler rather than contend with the difficulties of cleaning the water-tube type.

In more recent years these conditions have been greatly improved for the water-tube boiler in two ways.

First, by the very general introduction at large plants which do not possess a natural supply of good boiler water, of purifying plants which neutralize any injurious acid which the feed water may contain (this in coal-mining regions is sometimes a very large quantity), and then, by the addition of suitable chemicals, precipitate out a large part of the scale-forming material which the water contains, and throw that which is left into a form which makes sludge that can be blown out instead of forming scale. Without such treatment this material

settles on the tubes and other heating surfaces in a deposit almost as hard as iron, and almost as non-conducting as asbestos.

Second, by the introduction of power-driven boiler cleaners of various types. Generally the power is transmitted to the cleaner by water under pressure or by compressed air; the fluid under pressure in either case drives a motor small enough to go inside the tube and pass through it freely. This motor carries at its forward end steel cutters of various forms, generally loosely pivoted to the shaft of the motor and thrown out to the wall of the tube by centrifugal force.

The motor is run at a very high speed and the rapid whirling of these cutters removes the scale which is carried out of the tube by the "exhaust" of the fluid which drives the motor.

Much ingenuity has been employed both in making and in selling devices of this kind, and some of them are extremely meritorious. The motors in general are of two types, turbine and sliding-vane positive-pressure motors. It would be thought that this would be the ideal field for the turbine, but I have obtained the best results with the sliding-vane positive-pressure motor.

As between the two fluids, water and air, the advantages, in my judgment, are so strongly in favor of compressed air as to put it beyond comparison. This is for two or three reasons. First, the men working with the apparatus are at close quarters with it in a confined space, and no matter how carefully made and operated water-driven apparatus may be, under such circumstances it is impossible for the operator to avoid becoming wet and very dirty from the sludge produced by the grinding up of the scale. This makes the task an excessively disagreeable one for the operator, and materially reduces his speed in accomplishing it. Secondly, the exhaust water from the motor cannot be prevented from reaching the brickwork of the setting to a greater or less extent, and in the Babcock & Wilcox boiler it is almost impossible to prevent its running down into the underground flue with a bad effect upon both the draught and the flue.

With air none of these disadvantages exist. The air is perfectly clean, and its expansion even tends to cool to a small extent the air in the drums which the operator has to breathe, so actually ameliorating the conditions under which he has to work, while, of course, it has no effect whatever on the setting. Moreover, the amount of power needed may be transmitted through a much smaller hose with compressed air than with water, and therefore the hose which connects the motor with the supply of power, and by which it is pushed through the tubes, is correspondingly smaller, lighter and easier for the operator to handle.

By the use of the best types of these cleaners boiler tubes can be kept clean at the fraction of the expense and with a fraction of the time lost from service that are required when hand-cleaning is used.

Moreover, it is very much to be doubted whether hand-cleaning ever cleans the tubes so thoroughly as do power cleaners, no matter how conscientiously the former may be done.

I have seen the power cleaner applied to boilers supplied with the best natural feed water which had received the most thorough care, were thought to be absolutely clean, and were, as far as could be seen, but at certain points the cleaner found and removed scale a quarter inch or more in thickness, which had been entirely invisible from the ends, although these were straight tubes.

Owing to the short length of these cleaners they may be used on curved tubes as well as straight ones and are equally effective therein.

This goes far to remove the disadvantage under which the Stirling and other curved-tube boilers formerly labored and to put them on a parity from an operating point of view with the straight-tube types, but, of course, it does not remove their disadvantage in the matter of removing and replacing tubes.

The power boiler cleaner is like many other useful tools in that it must be used with care and discretion.

In order to cut the scale the cutters must be good tool steel, almost as hard as glass and very sharp. In order to be effective they must run at a speed of many hundred revolutions per minute. It is obvious that if allowed to run in contact with the bare tube in one place they would soon cut it away enough to weaken it seriously if not to cut it through entirely, and the operator must be carefully instructed and advised to prevent this.

These two developments of the past decade and a half — the feed-water purifying plant which keeps out of the boilers much of the scale-forming material, and the power-drive tube cleaner which removes that which gets in — have reduced to a fraction of their former amounts the time, labor, worry, and expense of boiler maintenance, increased their average efficiency and decreased the percentage of spares necessary. They have thus gone far to solve the problems of boiler operation at blast-furnaces.

CHAPTER IV

BLOWING APPARATUS

THE power first applied to blowing furnaces was that of water wheels, but something over a generation ago these passed out of use except at very small plants working under peculiar conditions, on account of the lack of water powers of sufficient capacity to drive furnaces with the increasing volumes of wind desired and increasing pressures which those volumes necessitated. This brought about the introduction of the steam engine for blowing purposes. The number of types of such engines, and the method by which they were applied to blowing purposes, was almost unlimited.

About thirty years ago one type became predominant and held the lead for a long term of years. This is known as the long-cross-head type. It consists of a vertical steam-cylinder with a vertical air-cylinder immediately over it, both pistons being connected to the same piston rod. The shaft passes immediately underneath the center of the steam cylinder with a fly-wheel at each end just outside the bed-plate which supports the whole. These fly-wheels carry crank pins exactly in line with one another so as to act as one.

The cross-head is fastened to the piston rod midway between the two pistons and extends parallel with the main shaft far enough for the wrist pins on its ends to come in line with the crank pins in the fly-wheels. The housings which support the air cylinder from the bed-plate are cut out in the center so that the cross-head can pass through, and carry on each side of the opening the slides which guide the latter and take up the horizontal component of the thrust of the connecting rods.

Modern designs of this type of engine are shown in Figs. 71 and 72. This engine has the advantage of securing a direct transmission of the stresses arising in the work of compression directly from one cylinder to the other, and also of having its pistons move in a vertical line and therefore avoids their dragging on the bottoms of the cylinders with resultant friction and wear, a condition which at one time was considered unavoidable with horizontal engines.

The engine is also compact; it requires only a small foundation and small space in the engine house. It is under the disadvantage of requiring two connecting rods, and of requiring very careful workmanship in securing the absolute correctness of alignment of the two crank

pins. It also labors under the disadvantages in regard to supervision to which all vertical engines are subject. The advantages were long sufficient to outweigh the disadvantages, and this type of engine held an absolutely predominant place for a long term of years, and while



Fig. 71. Southwark vertical long cross-head blowing engine.

changes in the conditions have brought about the development of many other types, these engines, when of modern design and economical type, are not only kept in use, but new engines of this type continue to be built in considerable numbers. It is, therefore, with the development of this type that the modern blowing engine has its real beginning.

At the time when these engines obtained their predominance outputs per furnace were small with consequent small requirements for volume of blast, and pressures were quite low, probably, on the average, less than one-half of what they are to-day.

As a result the power required per furnace was small and economy, as I pointed out in the last chapter, was a factor almost absolutely



Fig. 72. Installation of "Mesta" long cross-head steam blowing engines.

ignored. The small blast volume required made it possible for few engines of moderate size to supply the blast required for a furnace at a very moderate speed. Hence, there was little or no demand for high speed to cut down the number and size of engines required.

Under these conditions engines were always fitted with some type of self-actuating air valves, in which a slight difference of pressure within and without the cylinder operated both the inlet and the outlet valves in the

required direction, and when this difference in pressure was ended and then reversed, as the piston reached the end of its stroke and started on the return, these valves were closed by the return currents of air so set up.

With low pressures and moderate speeds these conditions of operation produced no bad results, especially as the pressure and temperature to which the air was raised by compression were low and therefore valve faces and piston rings could be made of leather and wood respectively, or of other natural fibrous materials. These materials, however, while perfectly satisfactory at low temperature, undergo chemical change with increasing rapidity as the temperature rises, and so the time came, as pressures increased, when such materials could no longer satisfactorily be used for these purposes.

This forced the substitution of metal faces for these valves and thus emphasized the two difficulties with automatic valves, which had gradually come to be understood. First, if these valves are operated entirely by the currents of air which pass through them, they do not seat themselves until these currents are reversed in direction, and then are brought to their seats with a violent shock at any but very low speeds. As long as leather could be used this shock was much cushioned by the leather, but when metal faces became necessary operation under these conditions became increasingly difficult.

Second, the area inside these valves on which the excess pressure operates to lift them from their seats is less than the area outside them, tending to hold them closed, by an amount equal to the area of the seat itself, which must always be a considerable percentage of the total area. Therefore, the pressure inside the valve must always be greater than the pressure outside it, in the inversed ratio of the internal and external areas, before the valve will open. This leads to a delayed operation of the valve and necessitates a much greater difference between the internal and external pressures than would otherwise be necessary with corresponding loss of power.

If in order to overcome the difficulty of having the valves slammed hard against their seats by the reversed currents, a weight or spring was applied to them to force them to their seats, the pressure due to this weight or spring must be added to the difference between the internal and external pressures, with corresponding further loss of power. It is obvious that as pressures rose and speeds increased these difficulties must be augmented.

There were also other conditions of great importance to be met. First, the clearance should be kept small so that as nearly as possible all the air displaced by the piston may be driven out through the discharge valves instead of simply being compressed into the clearance space, and then re-expanding at the beginning of the next stroke, to the exclusion of air which should be taken in from outside.

Second, the area of the valve openings must obviously bear a definite ratio to the area and speed of the piston so that a valve area which is quite sufficient to permit relatively complete filling and ready discharge of a given cylinder at a low or moderate speed may be quite insufficient for the same cylinder at a higher speed. It must be remembered particularly in this connection that these losses are frictional and therefore vary as the square of the velocity, so that a cylinder which will fill with two ounces of suction at thirty revolutions will require one-half a pound at sixty, and a pound and one-eighth at ninety.

To meet as well as possible these conditions of low clearance and large area, a great multiplicity of valves, both for inlet and discharge, were adopted, and this was standard practice for many years, there being in some designs more than a hundred such valves in each end of an air cylinder of moderate size.

With increasing rate of driving came increasing pressure, and this brought about another difficult condition. It modified the shape of the indicator diagram for the air cylinder very much for the worse, from the point of view of the engine. With a blast pressure of four pounds the piston travels only about 20 per cent. of its stroke before the air is compressed to the required pressure and begins to flow through the discharge valves, so that with reasonably good design of valves, the work done upon the air cylinder was quite uniformly distributed throughout the stroke and subject to a minimum of variation. With a blast pressure of twenty pounds the piston travels more than 50 per cent. of its stroke against a pressure which rises constantly more rapidly, with the result that about three-fourths of all the work of the stroke is done in its last half.

On the other hand, the older types of uneconomical steam cylinders used but little expansion and so the steam pressure was but little lower at the end of the stroke than it was at the beginning, and the drop which took place was quite gradual with no sharp or sudden changes.

The demand for increased economy grew, as has been pointed out in the last chapter, and this could only be obtained by one means, much more complete expansion of the steam. This means that under ordinary conditions nearly one-half of the total work of the stroke must be developed in its first quarter, exactly the opposite to the way in which it is consumed, the greatest portion, as we have just seen, being expended in the latter portion of the stroke.

Some form of equalizer has to store the surplus work done in the steam cylinder in the early portion of the stroke, and give it out in the latter portion, and this equalizer is the inertia of the fly-wheel and of the reciprocating parts, but it is obvious that in a running machine

which must have a certain amount of play in its moving parts a complete reversal of the stress from one direction to the opposite, somewhere near the middle of the stroke, could not contribute to its smooth and easy working.

It will be seen from the above that the conditions under which the blowing engine worked in the early days of the long cross-head type grew steadily worse with the development of modern furnace practice. As a consequence of these conditions it is probably safe to say that, next to the furnace itself, blowing engines have given more trouble and furnished more difficult problems to furnace builders and operators than any other portion of the equipment.

Air valves. — To meet the increasing difficulties to which changing conditions subjected the automatic types of valves, many designs of positively actuated valves were brought out, of which the test of time has left but few, and it is not possible in a single chapter to treat any except those which have had some considerable degree of industrial success.

Corliss valves. — The Corliss or semi-rotating valve had proved its serviceability, its relative ease of operation, and its tightness under long continued wear, by almost half a century of successful use in the steam engine, at the time when the development here under discussion began, therefore it is not surprising that this valve should have been one of the first applied to air cylinders. In its earlier form it was applied in almost the identical way that it was in the steam engine, except that the inlet valve in the air cylinder corresponds to the exhaust valve in the steam cylinder, as does the discharge valve of the air cylinder with the inlet valve of the steam cylinder.

A glance at the indicator diagrams, Figs. 73 and 75 showing steam cards, Figs. 74 and 76 showing air cards, will show that these are of the same general type and shape, but one is traced in one direction and the other in the opposite. One represents positive work and the other represents negative work, or energy absorbed. So the base line of one represents spent fluid discharged, and of the other incoming fluid to be compressed.

The inlet line of the air cylinder changes but little with changing conditions, that is to say, the times at which the inlet valve opens and closes are only slightly altered by changes in speed or pressure.

Theoretically the proper time of opening is changed slightly because the greater quantity of air in the clearance space at higher pressures expands to a greater volume at atmospheric pressure, and in order to recover all the energy due to the complete re-expansion of this air the inlet valve should not open until re-expansion brings the pressure of this clearance air down to that of atmosphere, which, of course, means that the inlet valve should open somewhat later with high

pressures than with low. But no practical or even appreciable loss is experienced under any ordinary condition, by having this point of opening fixed at the point to suit normal conditions.

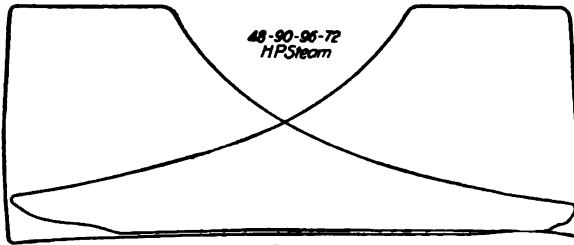


Fig. 73.

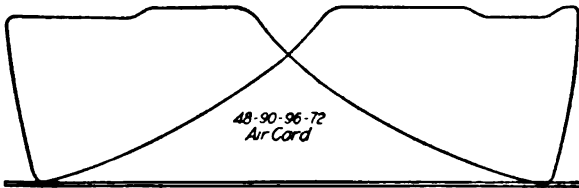


Fig. 74.

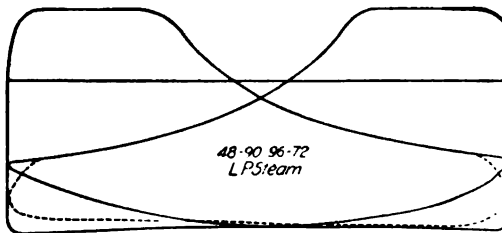


Fig. 75.

Figs. 73-76. Steam and air cards.

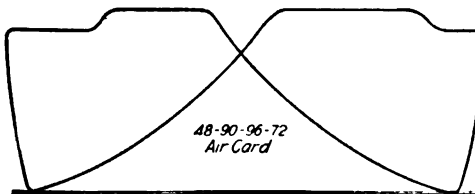


Fig. 76.

For these reasons the inlet valve is positively connected to the eccentric and opens and closes at predetermined points in the stroke. The discharge valve on the other hand ought obviously to open at a

different point with four-pound pressure from what it would for twenty, and it was long thought that it was necessary to put the opening of this valve under the control of some type of trip mechanism, akin in principle to the Corliss dash-pot, which was released by a small auxiliary cylinder in direct communication with the end of the main cylinder, so that as the pressure in the latter rose, the auxiliary piston tripped the releasing gear and the dash-pot pulled the valve open.

It was left for Mr. B. V. Nordberg, of the Nordberg Manufacturing Company, to point out that the loss by having the discharge open a trifle too soon was almost insignificant, in fact practically inappreciable even with very considerable changes in the discharge pressure, and he therefore builds blowing engines, in which both the inlet and the discharge valves are rigidly connected to eccentrics, timed to open and close them at the proper point for normal conditions. A clause in the contract for the first of these engines provided that if it should be found necessary, an automatic gear would be provided at small additional expense which would shift the point of opening of the discharge valves as the pressure rose, but the results from the engine in practice were almost absolutely perfect, and no conditions ever arose to cause regret at the omission of this automatic device.

Corliss valves have several great advantages. By a suitable design of valve gear they can be made to perform most of their travel at a time when the pressure on their opposite sides is approximately the same, so that they can be moved with a minimum of power and of wear, and owing to the "dead travel" obtainable with a proper design of wrist plate are almost stationary when the unbalanced pressure upon them is considerable. They are held against their seats by pressure, and follow them down as they wear, with the result that their tightness in service under good conditions is well maintained. They also permit large port areas with minimum clearance.

On the other hand they require a considerable quantity of oil for proper lubrication, and one large set of engines with this type of valves so designed as to require an excessive amount of oil to keep them in operation was probably more responsible than any other one condition for their failure to develop into a leading type of valve. In spite of this fact at least one engine with valves of this type is known to the writer which has been in virtually continual operation for twenty-five years and is in first-class condition now.

Pot valves. — The poppet type of valve has always been used for discharge valves and one of the first steps in replacing the Corliss valve for air cylinders was the introduction of a modified form of poppet valve which opens automatically, but is positively closed, an idea first brought out by the German engineer, Riedler.

This valve consists of a hollow steel pot drawn from a single piece

of steel. This pot is from sixteen to twenty inches in diameter and of approximately the same depth, with a spherical bottom surface; the metal in it is about a quarter of an inch thick in the bottom, and three-sixteenths of an inch in the sides. This closes against a suitable seat in the cylinder head close to the piston. Inside of it works a plunger; sometimes this plunger is the same diameter as the inside of the pot in which it acts as a piston, sometimes the plunger is of smaller diameter.

This plunger is operated by a rock shaft driven from an eccentric so timed that the plunger forces the valve to its seat an instant before

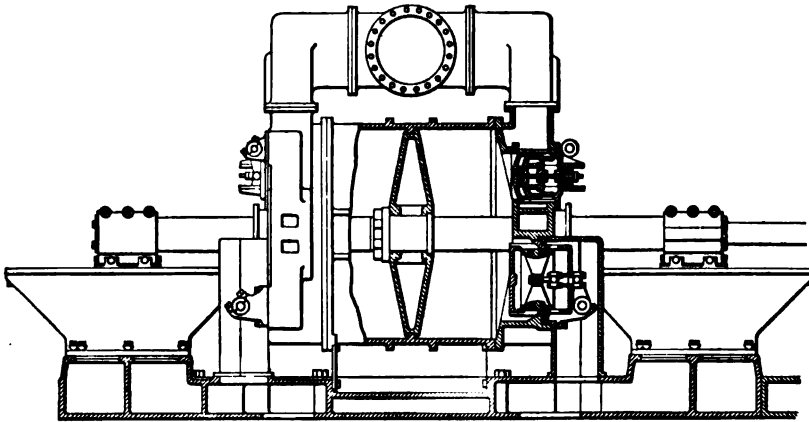


Fig. 77. Reynolds' poppet valve.

the crank passes the center and before any return current of air can be set up from the receiver back into the cylinder. The plunger is then withdrawn and the valve is held to its seat by the excess pressure within it, since it is provided with small holes around its circumference, just above the seat, which put it into constant communication with the air receiver, and which permit the escape of the air between the plunger and the cylinder, thus helping to bring it to its seat gently and without shock or jar.

One of these valves is shown in the upper portion of the right-hand end of Fig. 77. This type of valve has remained the predominant one throughout the period of supremacy of positively operated valves. The original form of this design was the invention of the late Edwin Reynolds.

Various types of air inlet valves were tried, all designed to keep the clearance down to a minimum and yet give ample area for the admission of air, not only to keep down the suction but to secure the complete filling of the cylinder before the beginning of the compression stroke.

Two of these designs were radical and interesting by their boldness. One was known from its inventor, Mr. Julian Kennedy, as the Kennedy inlet valve. It consists as is shown in Fig. 78, of a long slender cylinder passing entirely through both cylinder heads and the piston of the air cylinder, with suitable packing rings or glands in all three.

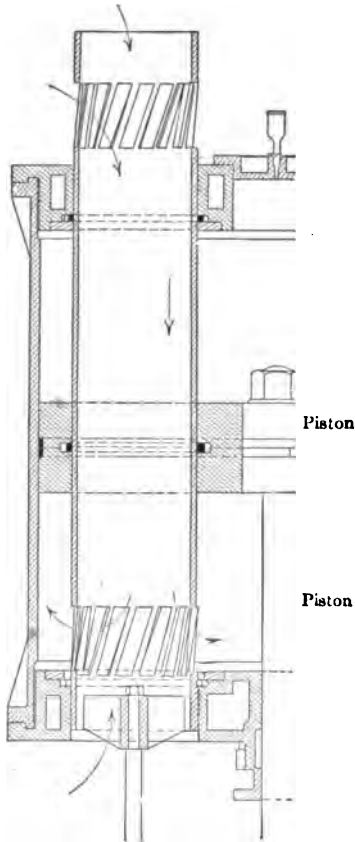


Fig. 78. Kennedy piston inlet valve.

This cylinder has near its upper and lower ends a system of ports cut through its walls on long spirals, one set for each end of the air cylinder. This valve is driven by an eccentric so that the ports in it are brought within the cylinder head during the admission stroke. Both ends of the valve are perfectly open to the air which passes in through its end and out through these ports into the cylinder. The valve is properly timed to open and close correctly at each end of the cylinder.

Fig. 78 shows a design in which this valve is set on one side of the cylinder and presumably in this case there are two of these valves. In the ordinary design there was one valve in the center of the cylinder, and the air piston was driven through two piston rods symmetrically spaced on each side of it, a design which has some merit.

The other design was the invention of Mr. E. E. Slick, formerly chief engineer of the Edgar Thompson Works, now Vice-President of the Midvale Steel Company. This was still more radical. The whole cylinder was perforated at each end with a set of ports

like those in the Kennedy inlet valve, and this cylinder was moved back and forth by a heavy rock shaft so that during each suction stroke these ports came within the inner surface of the corresponding cylinder head, these being rigidly held independently of the cylinder and making a sliding joint with it like the piston. This obviously gave the whole circumference of the cylinder for a port and yet the clearance due to inlet ports was absolutely nil. This arrangement is shown in Fig. 79; it has been successfully used for a number of years on large and particularly on high-speed blowing engines, but many engineers and furnace

operators objected to the awkwardness of the principle involved in sliding a cylinder weighing several thousand pounds back and forth through a travel approximating a foot at a rate of sixty, seventy-five, or more revolutions per minute.

The Kennedy valve also was disliked by many engineers and operators because of the great mass of metal to be pulled back and forth through a travel of nearly two feet, and at speeds up to fifty or sixty



Fig. 79. Slick blowing tubs at the central furnaces of the American Steel & Wire Co., Cleveland Ohio.

revolutions, also to the three moving joints necessary in that device, one in the piston, and one in each cylinder head. On several occasions these valves became detached from their driving mechanism and owing to their inertia, due to their weight and high speed, they generally made a wreck of serious proportions on such occasions.

A modification of this valve has been very successful. This is shown in the lower half of the right-hand air cylinder head in Fig. 77 and by Fig. 80. It consists practically of one end of the Kennedy inlet working in a short cylinder set in the main cylinder-head.

The air passes in this case longitudinally through the valve and then outward through the ports in the sleeve which carries it, and so into the main cylinder. The only disadvantage under which this valve suffers as compared with the Kennedy is the slight increase in clear-

ance necessary to carry the air from the ports in the sleeve into the cylinder proper.

The weight of the valve is only a small fraction of that of the Kennedy, and its travel is also much less, so that the inertia of this type of valve is almost insignificant in comparison with the inertia of the Kennedy valve and Slick valve types.

The construction is shown in the illustration.

The Southwark air valve.—The Southwark Foundry & Machine

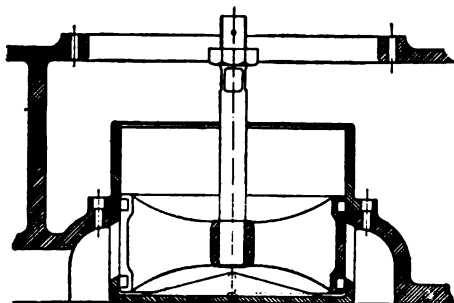


Fig. 80. Kennedy inlet valve.

Company had enjoyed for many years the reputation of pioneer builders of high-speed engines, having developed a system of balanced slide valves for the steam cylinder which could be put under the control of a governor, and permitted these engines to be operated at a higher speed than that attainable by any other type of large engine at the time when the modern de-

velopment of blowing engines began. They also appreciated the advantages of high speed from a purely mechanical standpoint, notably in regard to inertia stresses and the beneficial effects which they could be made to exercise upon the running of engines. This is a subject which we shall presently discuss.

These two conditions made it natural that the Southwark Company should desire to extend the benefits of their system of high speed engines to blowing engines, and they accordingly developed a system of positively operated valves arranged to open and close without shock and to provide ample port area for any speed at which blowing engines could be successfully operated. This system uses a multi-ported or a grid-iron valve both for inlet and outlet. The inlet valve is operated entirely by a cam driven by an eccentric. The inlet valve is on the inside of the head and is unbalanced because its movements take place only at times when the pressure on both sides of it is the same. The discharge valve is on the outside of the head and is balanced by a cover plate on its back. This valve is closed at the end of the stroke by a cam attached to the same mechanism as that which operates the inlet valve, but is opened by a small auxiliary cylinder in communication with the main cylinder, when the rising pressure in the latter during compression, equals that in the receiver.

A longitudinal section is shown in Fig. 81, and views of a cylinder head with its valves are shown from within and from without by Figs. 82 and 83.

It is probably no more than fair to say that this system of valves was the earliest of any of the mechanically operated valves to be developed into its present condition and at the same time remain in general use. It is also probably fair to say that this valve was the first to be used in this country at the high speeds which are absolutely necessary with gas-driven blowing engines, and which are very desirable with many steam engines.

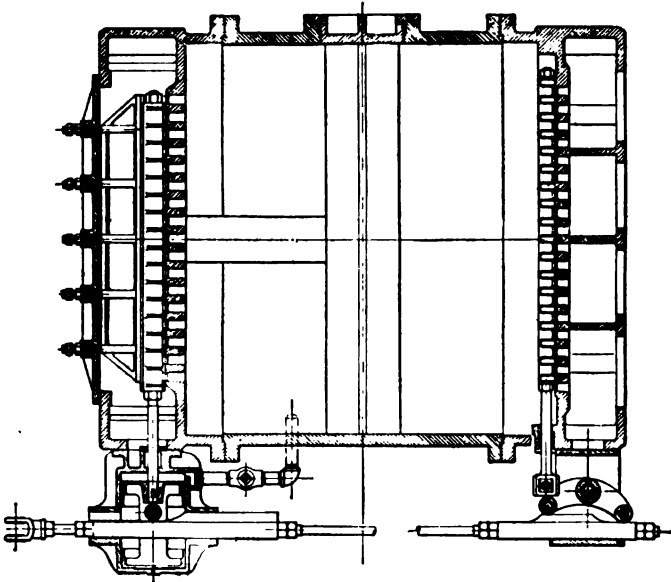


Fig. 81. Southwark air cylinder showing inlet and outlet valves, with gear.

The return to automatic valves.—The last two or three years have seen a development in this field which brings us back almost to the starting point. The gas-driven engine has received a great development in Germany and as the speeds at which it has to run in order to be successful are considerably higher than those customary with steam engines, the question of air valves has been one of great moment to the German engineers, and they have developed a system which modern workmanship and modern metallurgy have made possible. The design used by the American licensees of the Rogler patents, the Ingersoll Rand Co., is shown by Figs. 84, 85, 86, 87. The latter shows an 84 x 60 blowing cylinder head, equipped with these valves.

Each valve consists of three or more concentric rings held together by radial bars or bridges, the whole being stamped from a single thin plate of special steel.

The valve seat consists of similar but alternately spaced concentric rings, the openings between which constitute the ports and are covered

by the valve rings when closed. Four small helical springs in the cover plate serve to seat the valve.

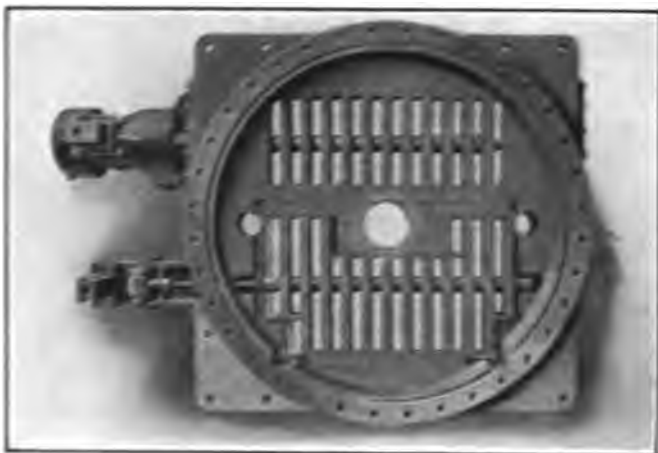


Fig. 82. Southwark air cylinder head, inside view.

The valve is extremely light in weight and requires but a slight lift to give full opening and its inertia is, therefore, very small.

For this reason the small tension of the springs is sufficient to seat the valve at the proper time without adding appreciably to the air resistance in passing through it.

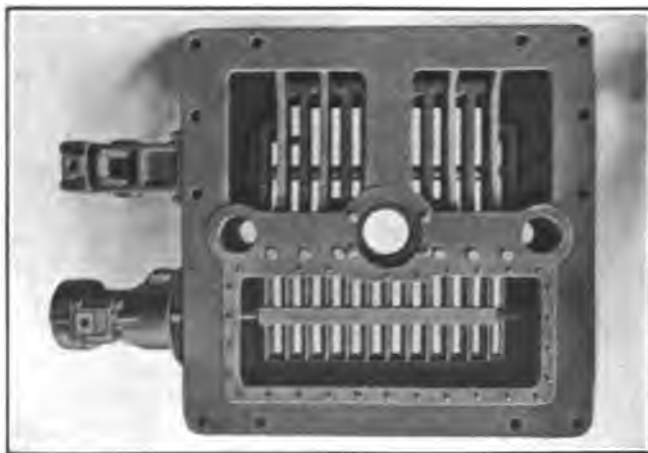


Fig. 83. Southwark air cylinder head, outside view.

The principle of this valve is not essentially different from that of the poppet valve of fifty years ago, but the details of the design are such as to constitute the difference between failure and success under modern conditions.

An American design of similar valves has been brought out by the Mesta Machine Company, of Pittsburgh, under the name of the Iverson

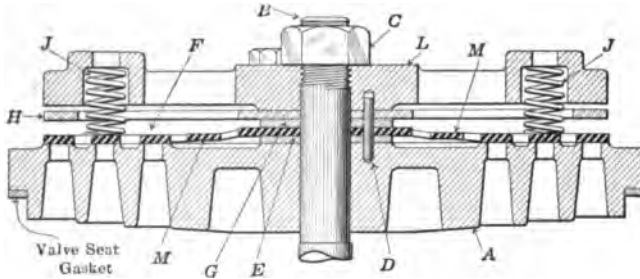


Fig. 84. Cross-section of Ingersoll Rogler Valve with seat, cap and springs.

Valve. These are shown in Figs. 88, 89, and 90. In this case the valve is independent of the spring, which is a flat spiral (not helical), spring, clipped to the back of the valve proper.



Fig. 85. Ingersoll Rogler Valve seat, cap, and springs disassembled.

The results with these valves in regard to providing the area necessary for inlet and discharge with minimum suction on the bottom of the indicator card, and minimum excess pressure on its top line, are claimed to be equal, if not superior, to the best of the mechanically operated

valves. The clearance is small and the operation of the valves is noiseless.



Fig. 86. Top and Bottom views of Ingersoll Rogler valve complete.

These valves have one advantage also which I should hardly have believed if I had not seen the results myself. In vertical engines the inertia of the eccentric rods, rock-shafts, and other mechanism for actuating the air valves is sufficient to cause some vibration in almost

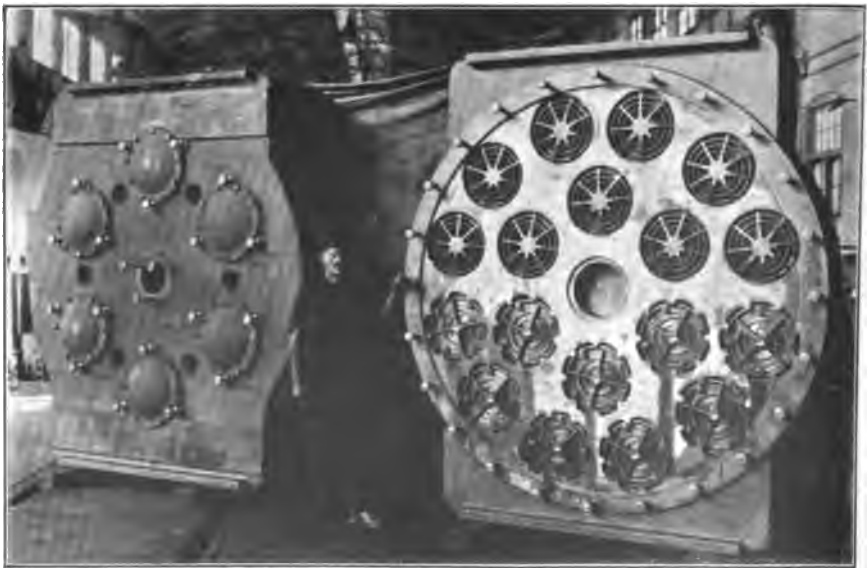


Fig. 87. Blowing cylinder heads equipped with Ingersoll Rogler Valves inside and outside views.

all engines, and in those of the steeple type this has in many cases been excessive. In cases where these small automatic valves have been substituted for mechanically operated valves, the entire absence of any

moving parts except these light valves themselves, which only move a fraction of an inch, eliminates this vibration.

I have seen engines running side by side, one vibrating almost dangerously and the other perfectly still. The manager who was then trying the valves out told me that the engine with the automatic valves had vibrated as violently as the other when it was positively operated.



Fig. 88. Valve plate and spring of "Mesta" (Iverson patent) automatic plate valve.



Fig. 89. Valve seat of "Mesta" (Iverson patent) automatic plate valve.

It is probably too early in this new development to say what its ultimate results will be, but if the promise of the present is fulfilled we shall probably witness, in the next few years, the elimination of much complicated and expensive mechanism from our blowing engines.

Methods of compounding. — The growth of the demand for economy in blowing engines, previously described, obviously required the introduction of compounding, to which at first sight the long cross-head type of engine did not adapt itself well.

The late John Fritz solved the problem by putting the high and low pressure cylinder of the compound side by side over the shaft in the position previously occupied by the single cylinder, and connected both piston rods to the long cross head, the position and parallelism of this being rigidly controlled by the connecting rods at its outer ends, by which the continually varying differences in pressures in the two cylinders were absorbed, apparently without injurious racking stresses on the engine.

A single air cylinder was used, as with the simple type of engine, its piston rod being connected to the center of the long cross head as before.

This type of engine, however, never received general favor, and,

consequently, other types were developed which adapted themselves to compounding. The principal types are the horizontal cross-compound with tandem air cylinders, the vertical cross-compound with tandem air cylinders, known as the steeple type, the cross-compound horizontal vertical engine having horizontal steam cylinders working on two cranks at right angles, with the air cylinders vertically over these cranks and driven by them, the quarter crank vertical engine with steam and air sides entirely separated except for the crank shaft which connects them, and the disconnected compounds.

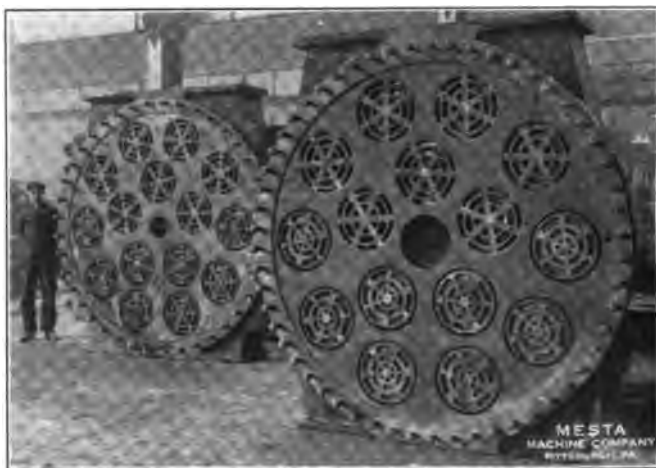


Fig. 90. Air heads equipped with "Mesta" automatic plate valves (Iverson patent).

Before we can discuss these different types of engines intelligently the subjects of the inertia of the reciprocating parts and engine friction must be briefly treated. The subject, as applied to the steam engine, will be found in any good treatise on that subject, but the power-generating steam engine is very different from any type of blowing engine in which the air and steam pistons are connected to the same rod, for the reason that in the power engine all work generated in the cylinder has to pass through moving parts, the cross-head pin, crank pin and main bearing, into the crank shaft, from which the useful effect is delivered. In the blowing engine on the other hand, where the steam and air pistons are rigidly connected to the same rods, the energy generated in the steam cylinder is transmitted only through a rigid member directly into the air cylinder, except, as has been pointed out, that most of the work is generated in the steam cylinder in the early part of its stroke, and the principal utilization in the air cylinders occurs in the latter part of the stroke.

It is obvious that the excess above that immediately utilized in the air cylinder must be stored either in the fly-wheel or in the reciprocating parts and given out again to make good the deficiency in the latter part of the stroke. The transmission of these excesses and deficiencies through running parts affects seriously the friction of the engine, which is important not only on account of the power so lost, but because the power lost represents destructive energy applied to the moving parts of the engine itself, and for economy of maintenance, even if not for economy of power, this should be kept as low as possible.

It is probably true to say that the friction of a well-built reciprocating steam engine is about 10 per cent. of its indicated horse-power at its rated load, while when running idle, but up to speed, the friction is about one-half of this, that is, about 5 per cent. of its rated power.

It is obvious, therefore, that if we can take part of the energy developed in the steam cylinder and apply it directly without its having to pass through the running parts to the fly-wheel, we shall make a considerable saving in friction, and, consequently, in wear.

Inertia of reciprocating parts. — This is not the place for an extended discussion of the subject of the inertia of the reciprocating parts, which is a mathematical problem of no mean order if it be handled completely and accurately. For our purpose, it is sufficient to say that the inertia of the reciprocating parts at the end of their stroke exert a force equal to the centrifugal force of an equal weight hung on the crank pin, and in the same direction, that is, outward from the center of the crank shaft. Starting at this value at the beginning of the stroke, the inertia diminishes in the same proportion as the distance of the piston from the center of its stroke, at which point the inertia becomes zero. Then, as the piston approaches the other end of the stroke the inertia effect rises from zero to an equal amount in the opposite direction.

It is obvious that this inertia always acts outwardly from the crank shaft; that is to say, at the head end of the stroke it acts toward the head of the cylinder, and at the crank end of the stroke it acts toward the crank end of the cylinder. The fact that this force increases from zero at the center to a maximum at the ends, and then decreases down to the center again on a straight line diagram, should be emphasized because it is often supposed by those who have not studied the subject that this force is exerted only at the end of the stroke. Nothing could be further from the truth.

The statement of the exact proportionality of this force to the distance from the center of the stroke is exactly true only when the connecting rod is of infinite length, or when the slotted cross-head or Scotch yoke is used, which, of course, is never done with blowing engines. With connecting rods of finite length the inertia effect is greater at the

head end and less at the crank end than the amount stated, by that fraction which expresses the ratio of the crank-throw to the connecting-rod length. This, while a matter of some importance to designers, is not of sufficient importance for our purpose to necessitate its being taken into account, as the assumption of the straight line diagram for the inertia effect is sufficiently accurate for our purposes.

It will be obvious from what has been said that this inertia effect tends to absorb energy from the steam cylinder in the early part of the stroke, when energy is required to accelerate these moving parts, and to give it out again in the latter part of the stroke, when these parts are being retarded by the movement of the crank. This means that the reciprocating parts are taking up energy at a time when the steam cylinder has it to spare, and giving it out at a time when the air cylinder needs it.

In order to investigate this effect quantitatively in relation to the air and steam pressures, it is necessary to determine the total inertia effect and then consider it as distributed over the air piston as if it were a force of so many pounds to the square inch. Similarly, we can reduce the pressure of the steam cylinder in the ratio of its area to that of the air cylinder, and so put all three of these forces on the basis of a common unit, of pounds per square inch of air-cylinder area.

Through the kindness of the William Todd Co., of Youngstown, I have obtained sets of indicator cards from the air and steam cylinders of steam-blowing engines, and also similar cards from a gas-blowing engine. They have also given me the rated speeds of these engines and the weights of the reciprocating parts, as well as the diameter of the various cylinders and the strokes.

These diagrams for a horizontal cross compound blowing engine with forty-eight-inch high-pressure cylinder, ninety-inch low pressure, ninety-six-inch air cylinders and sixty-inch stroke in common are those shown in Figs. 73, 74, 75, and 76.

These cards were taken to represent approximately simultaneous conditions in all the cylinders. The rated speed of this engine is forty revolutions, the weight of the reciprocating parts on each side is approximately sixty thousand five hundred pounds.

From these I have laid out what may be called the resultant diagrams of all three forces, that in the steam cylinders, that in the air cylinder, and that of the inertia — all reduced to pounds per square inch of air-cylinder area, which are shown in Figs. 91, 92, 93, 94.

There are obviously four sets of such resultant diagrams for such an engine, one representing one stroke in each direction and on each side, but as all of these are more or less similar one will be sufficient to show the principle involved.

We first have to combine the diagrams as taken which represent the

conditions throughout the cycle of one revolution in each end of each cylinder and combine them into "net pressure" diagrams for the steam and for the air cylinders by deducting from the pressure in one direction, the *simultaneous* pressure in the opposite end of the cylinder

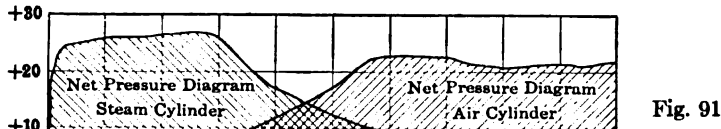


Fig. 91

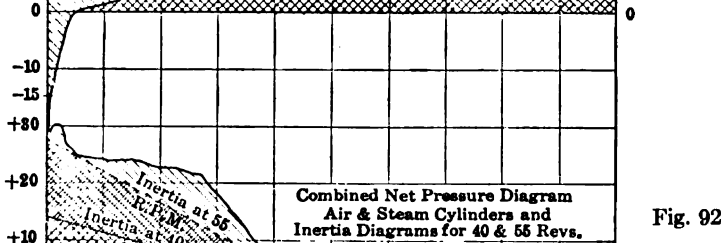


Fig. 92

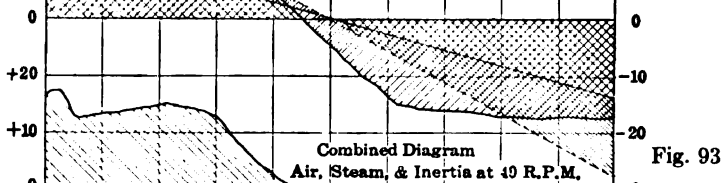


Fig. 93

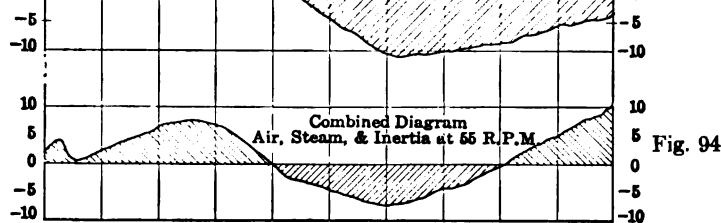


Fig. 94

Figs. 91-94. Diagrams, of steam, air, and inertia combined.

in the opposite direction, this subtraction being made in the algebraic sense. These two net pressure diagrams are shown in Fig. 91, the pressures of the air diagram being in the opposite direction to those of the steam diagram. Ordinates below the line represent pressure in the opposite direction to that represented by ordinates above the line.

We can obviously combine these two diagrams into one by subtracting the ordinates of one from those of the other in the algebraic sense. The result of this operation is shown in Fig. 92, which shows that the pressure is entirely in one direction during one-half of the stroke, and suddenly changes to the other near the middle of the

stroke. On this diagram is shown, as a solid straight line passing through the center, the value of the inertia per square inch of air-cylinder area, for forty revolutions, and in dotted lines that for fifty-five revolutions.

Remembering that ordinates of the inertia diagram above the zero line on the left-hand side of the diagram mean energy absorbed, and those below the line on the right-hand side of the diagram mean energy given out, we can obviously deduct these ordinates from the net-pressure ordinates of the combined diagram for air and steam, and the result will be the final net pressure transmitted to the crank pin. The result of this subtraction is shown in Fig. 93 for forty revolutions, while Fig. 94 shows the result which would be obtained on a similar basis if this engine were run at fifty-five revolutions instead of forty.

It will be obvious at a glance that the energy represented by the triangular area of the inertia diagram has been subtracted from the energy imparted to the fly-wheel in one part of the stroke and subtracted from that given out from the fly-wheel in another part of the stroke, the result being that the energy transmitted through the running parts at forty revolutions is only about one-half of that represented by the total work done, and would become an almost insignificant amount at fifty-five revolutions.

It may be thought that these considerations are too theoretical to be of practical importance, but I have seen large blowing engines in poor condition which would make a noise almost like steam hammers when running at a low rate of speed, but which would quiet down when the speed was increased until at a speed as high as the valve gear would stand they would run silently and well. Moreover, the Southwark Company has designed blowing engines on this principle for many years which have run as successfully as those of any other maker, and more successfully than those of some builders, who use much lower speeds because they are afraid of the higher ones.

The Nordberg Manufacturing Company also has built blowing engines, some of them to the specifications of the writer, which were designed on this principle. They had a relatively short stroke, and ran at a high rotative speed, and so obtained the displacement of a much larger engine at a lower speed. These engines were properly proportioned as to the inertia stresses and ran with the most perfect smoothness and absence of all pounding and noise at high speeds, seventy-five and eighty revolutions, as well as at lower ones. These facts have a most important bearing upon the design of blowing engine to be preferred.

The disconnected compound. — The problem of compounding blowing engines has been solved in the case of several of the types of engines above described, by building two separate units, one driven by the

high-pressure steam cylinder, the other driven by the low, these units being connected only by the steam receiver. These engines are thus enabled to run as compounds and enjoy the benefit of that system, and at the same time retain the flexibility due to small units, because each engine can be run separately. The high-pressure engine has two dispositions for its exhaust, one to the receiver and the other direct to the condenser, or atmosphere. Then, if the low-pressure engine is not needed, or needs repairs, it may be shut down and the high-pressure then exhausts direct. Similarly, the low-pressure unit has a double source of steam supply, one the receiver steam from the high pressure, the other, live steam throttled through a reducing-valve, so that this engine can be run entirely independent of whether the high-pressure unit is in operation or not.

This type of compounding has been applied to the horizontal tandem, the quarter-crank vertical, to the horizontal tandem, and particularly to the long cross-head types of engines. In fact, for several years the long cross-head type of engine regained at least in part its old preëminence through the introduction of this system.

When this system is used one engine may be used on one furnace and the other on another, if desired. Where three cylinders are required to blow a furnace, as is not infrequently the case, six of these units, constituting three complete compounds, blow two furnaces, one complete unit on each furnace, the high-pressure of the remaining unit on one furnace and the low on the other. The arrangement of the valves is such that if one furnace is to be shut down, or if the blast be taken off for even a short time, the exhaust valves on the high pressure can be operated simultaneously, the receiver exhaust being closed while the direct exhaust is opened; the steam valves on the low pressure can be similarly operated so that either half of the unit may be kept going on its furnace irrespective of what the other unit is required to do. The governor operates on the high-pressure cylinder only and the cut-off of the low-pressure unit is regulated by hand to bring its speed the same as that of the high pressure. This adjustment will hold for a considerable variation of pressure without very much variation from the desired speed on the part of the low-pressure unit, when both are on one furnace, and, consequently, blowing against the same pressure, but when the two units are used on different furnaces whose pressures vary in different ways, the conditions are not so simple and more frequent adjustment of the cut-off on the low-pressure unit is required.

The writer designed several years ago a means whereby these engines could be made to run at the same speed irrespective of the conditions under which they operated, but the manufacturers took no interest in introducing the device, and nothing was ever done with it.

Review of different types of engines. — We may now review these different types of engines in the light of the general conditions set forth above, and pass on their desirable and undesirable characteristic.

The vertical quarter-crank engine. — This engine, shown in Fig. 95, is built in practically the same design by several of the best builders,

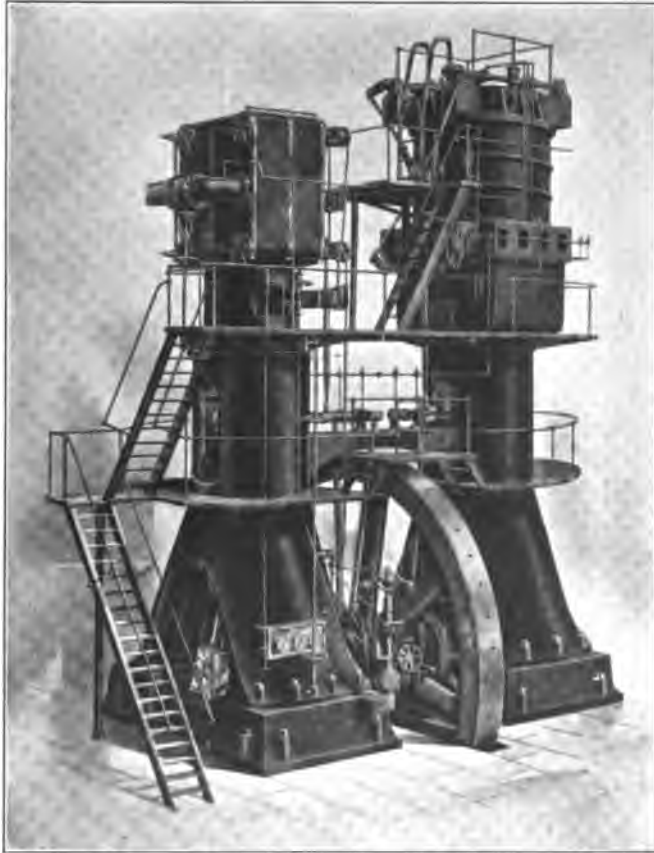


Fig. 95. Vertical quarter crank blowing engine, 42-in. steam, 84 air x 60 stroke.

and is not, as far as I know, recommended particularly by any of them. I shall not, therefore, do any injustice to any of these builders when I say that in my judgment this is the poorest type of blowing engine in regular use to-day. A certain measure of accessibility is obtained by the fact that it has no tandem cylinders, but it requires a considerable amount of space, a much larger foundation than a long cross-head engine of the same capacity, and an equal if not greater height, while its running parts are very inaccessible for handling with a crane.

The principal objection, to it, however, is that it has two complete sets of running gear with their high first cost and maintenance, and that all the energy developed in the steam cylinder has to be transmitted through running parts into the crank-shaft and then from the crank-shaft through another set of running parts into the air cylinder. Taking the mechanical efficiency of a standard steam engine at 90 per cent. and the mechanical efficiency of a crank-driven compressor at the same, we have an efficiency for this engine of 81 per cent. as against 91 to 93 per cent. that may be and is secured in regular practice with the tandem-connected machine.

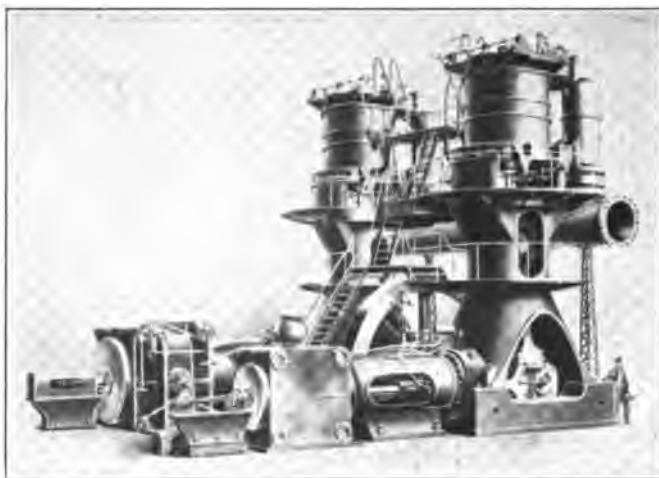


Fig. 96. Horizontal-vertical cross-compound, 52 in. and 90 in. steam, 90 in. and 90 in. air x 60 stroke blowing engine the Wm. Tod Co.

It is well to remember that this 19 per cent. of friction loss as against 8 per cent. in the other case, represents not only a loss of power but an expenditure of energy for destructive purposes which must reappear in the form of wear of two sets of heavily stressed running gear instead of one set lightly stressed.

This can, in my judgment, mean in the long run only one thing, high maintenance and repair cost, which, coupled to the high first cost of this type of engine with the consequent high fixed charges, all tend to make this an undesirable type from the technical, operating and financial points of view.

The horizontal-vertical. — The horizontal-vertical, shown in Fig. 96, presents almost the same conditions, though these are offset by the fact that the running balance of these engines, if properly made, is excellent, and therefore their steadiness on their foundations very great.

On the other hand, the horizontal-vertical requires as much height and much greater foundation than the quarter-crank vertical.

Many years ago the late P. L. Weimer, realizing that the energy of the steam was mainly developed in the early part of the stroke, and absorbed by the air mainly in the latter part of its stroke, built what are now known as horizontal-vertical engines, with horizontal steam cylinders and vertical air cylinders, both working on the same crank pin. With this arrangement the earlier part of the steam stroke obviously takes place during the latter part of the air stroke and vice versa. Consequently, a certain equalization of the work absorbed and expended from instant to instant is made, which justified in part the use of this type when speeds were low and inertia effects negligible.

In later years these engines have been built by other builders in very large sizes, and are favorably considered by some operator, although the inertia effect with moderate speeds makes this design wholly unnecessary. In these engines, also, it is obvious that the total work generated in the steam cylinder must be transmitted to the crank pin with a friction loss of some 10 per cent. and then transmitted back from the crank pin through another set of running parts to the air cylinder. It is reasonable to assume that here also there is a loss in friction of 10 per cent., making the mechanical efficiency of this engine also, as a whole, only about 81 per cent.

I have unfortunately no figures giving the mechanical efficiency of these engines in service, but there is no reason to expect that it is much higher than the figure given. On the other hand, with the direct-connected steam and air pistons of the horizontal tandem and a proper proportioning of the cylinder diameters, speed, etc., it is obvious that only about 20 or 25 per cent. of the total energy need be transmitted through the running parts, and that the friction of the engine accordingly should be only 6 or 7 per cent. instead of 19, as in the other case.

In confirmation of this, which may seem an extreme statement, tests have been made on Nordberg compressors designed to make use of this principle, which had a mechanical efficiency of 95 per cent. at full load.

There is, however, one feature of the horizontal-vertical engine which deserves attention. It is evident from what we have said above that the inertia of the reciprocating parts can be utilized to reduce the stresses in the running parts very greatly. Nevertheless the inertia stresses due to these heavy parts which move at high velocities alternately in opposite directions, exist in the machine as a whole and tend to shift it back and forth on its foundation in the case of the horizontal engine without counterweight, or to pull the crank shaft up and down with an equal force if full counterweight be used, these conditions being reversed in the case of the vertical engine. But when two sets

of reciprocating parts at right angles work on the same crank, the inertia effect of one set is horizontal and that of the other is vertical, these components combine into a single constant stress in a direction exactly opposite to that of the crank, so that by counterweighting completely one set of the reciprocating parts, the horizontal-vertical engine runs in almost perfect balance.

Where foundations are bad and engines must be set upon piles driven through mud to the bedrock, these considerations are of much importance, and this type of engine is the best adapted of any to prevent serious shaking of the engine and its foundation or even the whole surrounding country for a distance of many hundred feet, as has happened at one large plant where the horizontal blowing engines were supported on piles.

The long cross-head type. — This engine requires small foundation and small space for a unit of given size, the vertical height required being about the same as that of any other type of engine with reciprocating parts in the vertical plane except the vertical tandem, or steeple type, which is much higher. The stresses in these engines are, of course, transmitted with great directness from one piston to the other, and through rigid parts, but there is a prejudice on the part of some engine builders against running these engines at a speed which would bring the inertia effect of their reciprocating parts up to the best point for smooth running and low wear. The exact reason for this disinclination I have never been able to discover, and it is only fair to state that it does not hold with all builders, some of whom build engines of this type to run up to seventy or seventy-five revolutions.

There is no doubt that when run at proper speeds and when built sufficiently strong to withstand vibration, this is a useful, reasonably inexpensive and satisfactory type of engine, capable of giving reliable service for long periods at a stretch, such as is needed in blast-furnace work.

It is, of course, open to the objection which exists with all vertical engines, that supervision, inspection and repairs are much more difficult and expensive than they are with horizontal engines.

The steeple type or vertical tandem cross-compound. — A design of this type of engine built by the Southwark Machine Company is shown in Fig. 97, while nearly all of the prominent builders build this type of engine on demand; the design of valve gear, etc., being different with the different builders, but the general type of construction being the same.

The great objection to this type of engine is its great height with the consequent difficulty of securing adequate inspection and care, and its liability to vibration owing to its height and the elasticity of its small base. It will be seen in the illustration that there are four plat-

forms above the main floor, all of which must be frequently visited for adequate inspection and care of the engine.

It is not to be denied either that these engines are exceedingly difficult of repair. Even where a crane is available, as it should always



Fig. 97. Southwark steeple blowing engine-quarter crank compound.

be in a modern blowing-engine house, there are many parts which it is impossible to reach with the crane without great difficulty, so that this virtually involves partly dismounting the engine for certain repairs. With the limited room available for this work on the platforms it can only be done at a disadvantage, and as a consequence repairs on en-

gines of this type are more difficult, slower, and more expensive than they are on a horizontal engine of the same size.

In regard to speed, the engine stands on a relatively small foundation and with its great height excessive vibration is likely to be set up even at very moderate speeds, and this type of engine therefore cannot in general obtain those advantages of high speed which are available to some other types, with consequent loss of efficiency from not having the most desirable resultant diagram of steam, air, and inertia pressures.

The horizontal cross-compound with tandem air Cylinders. — This type of engine, shown by Figs. 98 and 100, is open to the disadvantage



Fig. 98. Large horizontal cross-compound blowing engine. The Wm. Tod Co., Youngstown, Ohio.

that it requires the largest and most expensive foundation of any steam-blowing engine, and that it requires also a great area of building and ground, leading to high cost on this account, but the building cost as a whole is not so excessive as might be expected because of the very moderate height required with this engine, so that only a relatively low building is needed for its accommodation.

Its great foundation also acts as a huge anvil to absorb inertia stresses and unbalanced centrifugal effects of counterbalance. This tends to cut down to a minimum the possible vibration of the unit as a whole.

Owing to these considerations the engine is capable of being run at the speed best adapted to produce the highest economy, and this higher speed of unit permissible as compared with most other types of engines goes far to offset any disadvantages in total first cost under which a unit of this type of a given size labors, as compared with that of some other types. The whole of the engine is down on or near the ground level, and I believe that operators who have had experience will bear me out in saying that one attendant will look after two engines of this type more effectively than two attendants can after one of the steeple type of the same size.

This engine has, of course, the desirable feature of transmitting the

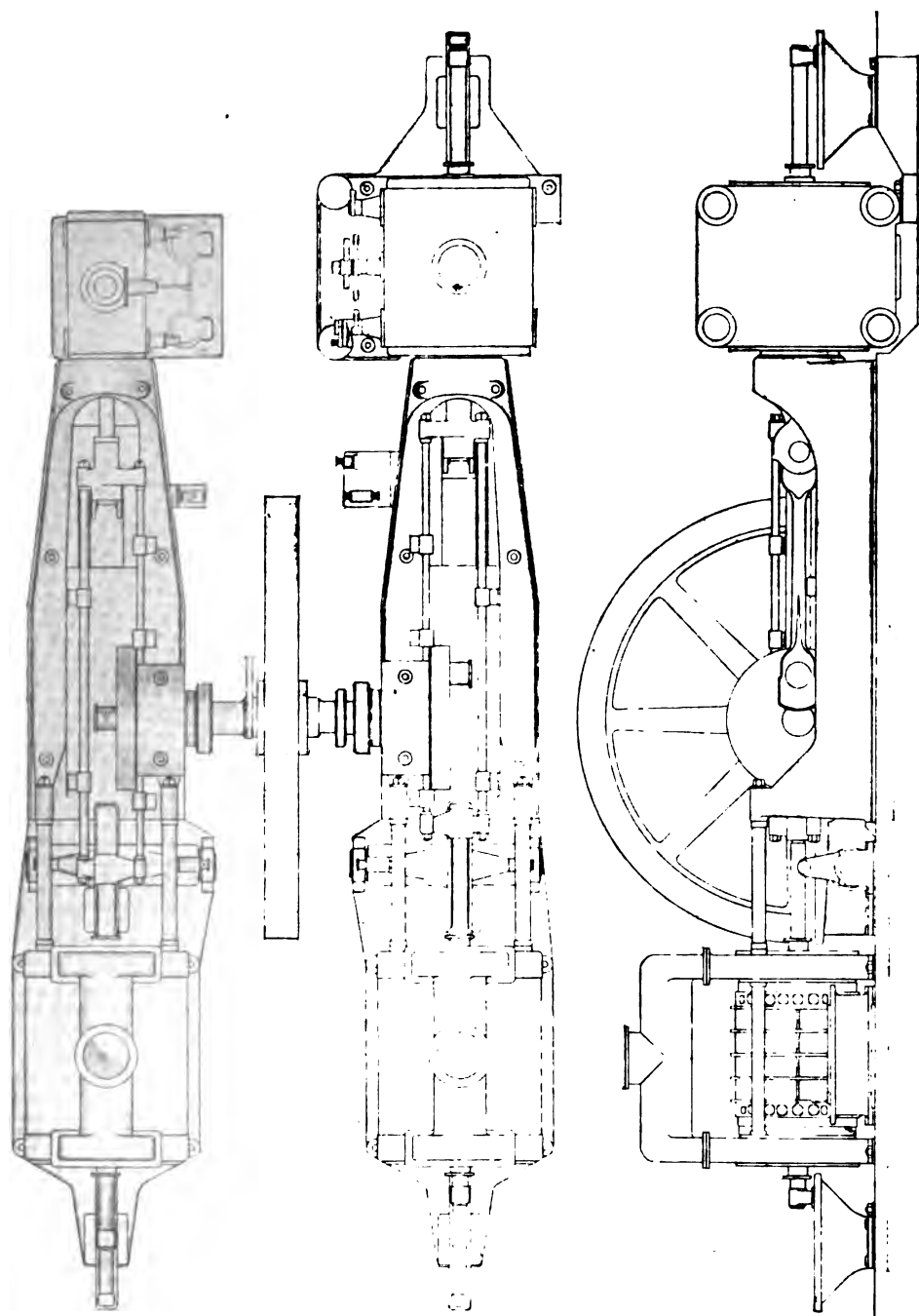


Fig. 99. Inside-crank blowing engine. Slick air cylinders 36 in. and 72 in. x 54 in. steam, 72 in. and 72 in. x 54 in. air. Allis-Chalmers Company.

stress from one cylinder to another through rigid members and not through moving joints, and in consequence it is capable of realizing the benefits of this system to the maximum.

Through the kindness of Mr. E. T. Child, of the Southwark Machine Company, I am able to reproduce in Fig. 101 a set of steam and air cards, one of a large number of sets taken by him personally from an engine of this type, running at a proper speed, in which the efficiency for the average of the whole set was about 91 or 92 per cent. This was in actual operation, no particular attempt being made to obtain a record, and I have no doubt that other well-designed engines of this type would do as well, if run at the proper speed.

The tail slide. — One of the essential features in the design of the modern horizontal cross-compounds is the means for relieving the bottom of the cylinders of the drag of the heavy pistons necessary in large units. This is accomplished by putting a cross-head and slide at each end of each of these large cylinders and making the piston rods strong enough to carry the pistons clear of the cylinder, so that nothing but the packing ring touches the wall of the cylinder.

In some cases the piston rods are made of high-grade steel and cambered upward before use to the amount by which the weight of the piston will deflect them so that they are perfectly straight in service.

Mr. Nordberg has gone still further and uses a hollow cast-iron trunk of large diameter whose only function is to carry the weight of the piston and take compression stresses, the tension stresses all being taken by a much smaller steel rod through the center.

This design not only frees the engine from a very heavy friction load, but also relieves the cylinders from wear and puts them on a parity in that respect with vertical cylinders.

The inside-crank engine. — The inside-crank type of engine is shown in Fig. 99. The crank-shaft lies between the two cylinders and the piston rod instead of passing directly from one cylinder to the other; is divided into two parallel rods symmetrically placed with reference to the axis of the cylinders, and in a plane about 45 deg. from the horizontal.

These two parallel rods take hold of suitable projections which are provided on the cross-heads for each cylinder.

This arrangement makes an uninterrupted open space in the axis of the engine and between the two cylinders; the connecting rod and crank work in this space.

The type shown is built as a cross-compound steam engine and this type of construction is also much used in gas engines. It has many of the advantages of the horizontal tandem engines, but on account of the stretcher rods from one cross-head to the other the simplicity and accessibility of the running gear are not so great as in the straight tan-

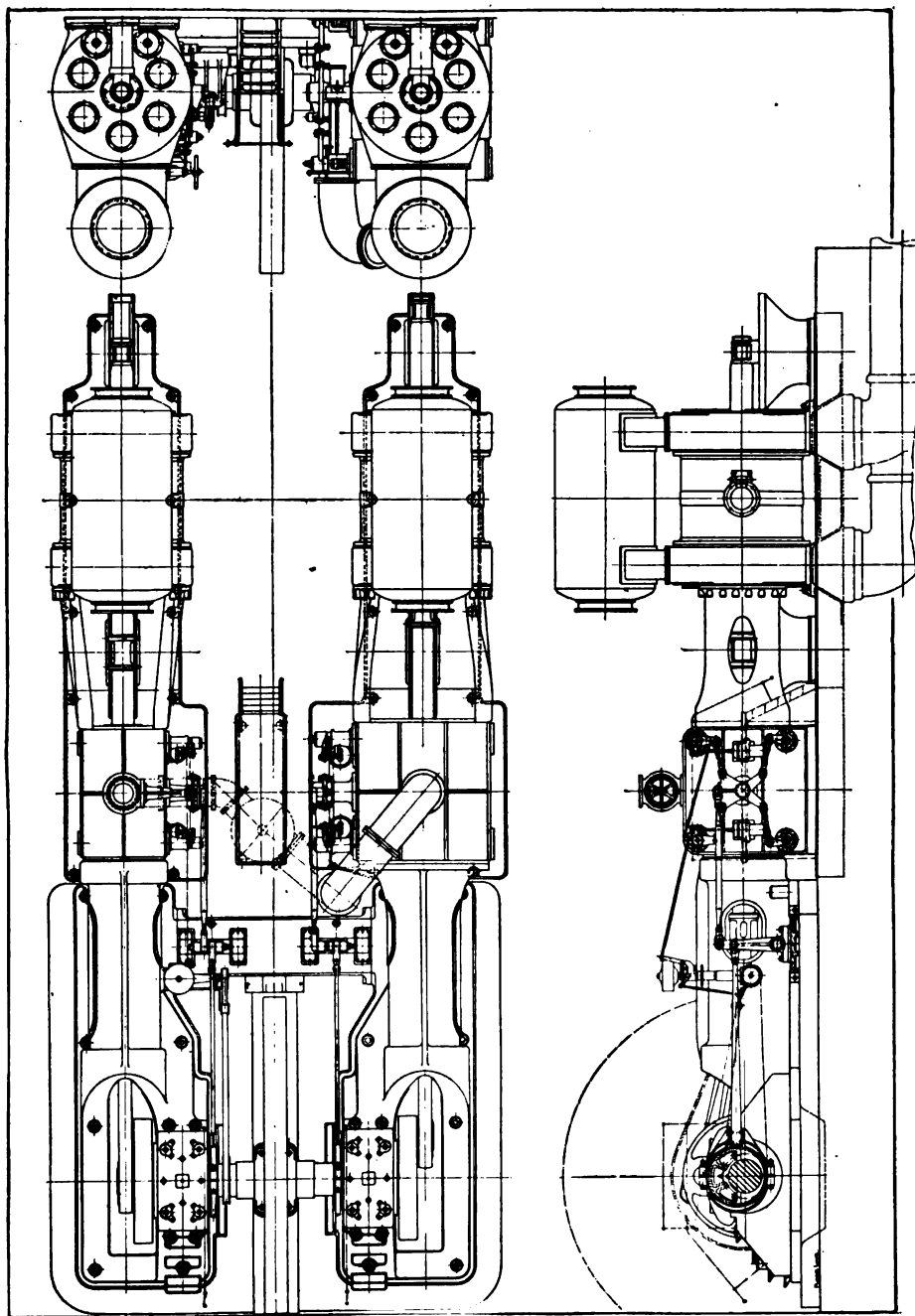


Fig. 100. "Mesta" cross-compound steam blowing engines.

dem type, and I have never known what advantages this engine possessed to offset these disadvantages unless it be the accessibility of the cylinders due to the elimination of the tandem arrangement. It is a type of engine approved by engine builders very generally, and is recommended by them for high speeds.

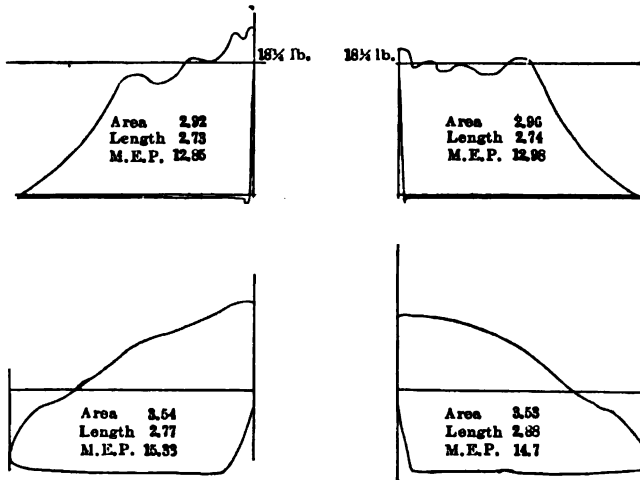


Fig. 101. Southwark steam and air cards showing a mechanical efficiency 92 per cent.

Steam valves and their settings. — The conditions as to the steam valves for blowing engines are no different from what they are in any other type under similar conditions of size, speed, and economy desired. It is therefore obviously unnecessary and undesirable to go into an extensive discussion of this subject here.

In American practice the Corliss valve has won its way to almost exclusive use in high-grade steam engines. The poppet valves, which have given magnificent results in Europe, have never become popular in this country in spite of the economical results which have been obtained with them. It is probable that the conditions of operation are somewhat more exacting with that type of valve on account of its coming against a rigid seat, than they are with the Corliss valve with its rotating motion and absence of sudden stops. At all events the result is as stated, that the Corliss valve gear is preëminent in all the modern blowing engines in service and being built in America at this time.

The original Corliss valve gear was the subject to the disadvantage that if the cut-off did not occur at a point somewhat before half stroke it did not occur at all, and steam followed full stroke with utter destruction of economy and terrific stresses on the engine.

With engines on constant mill loads, and particularly before the

introduction of the compound which divided the expansion between two cylinders and greatly retarded the point of cut-off in each, this was generally not objectionable, but with the relatively late cut-off necessary for the compound engine, the variable loads to be met, and variations in the steam pressures owing to irregular conditions, so limited a cut-off was not satisfactory for blowing engines, so that for several years makers have been adding an eccentric which enables cut-off to take place under the control of the governor at any point up to about eight-tenths stroke in the high-pressure cylinder, and this constitutes a great advantage under operating conditions, so much so that no engine should be installed for furnace work without it.

Theoretically the low-pressure cylinder does not need the long range cut-off so much, but practically the necessity of operating even though steam pressure be down, and the low-pressure cylinder doing most of the work, makes it very desirable to have this gear on the low-pressure cylinder also, and personally I should not recommend any furnaceman to buy a blowing engine not so equipped.

This feature is also of great advantage in starting an engine up from any position in which it may stop, without barring it over, and in a heavy engine this is a convenience well worthy of the expense.

The resultant diagrams, Figs. 91, 92, 93 and 94, indicate certain features as to the stresses in engines which are worthy of attention. It is proper to say that engineers are by no means unanimous on some of these points, and for that reason the views which I shall express are simply my own and are undoubtedly not in accordance with those of some others well qualified to pass on the subject.

There will be seen at the left of Fig. 91 a sharp point extending about 20 lb. per sq. in. below the line of zero pressure at the beginning of the stroke, which runs down to nothing at about 5 per cent. of the stroke. This pressure comes from the re-expansion of the air left in the clearance space of the air cylinder, and, of course, is *in the same direction* as the pressure of the steam in the steam cylinder at that time. As soon as the pistons have moved a short distance this air re-expands down to atmospheric pressure, and thereafter the rising pressure in the other end of the air cylinder is increasingly opposed to the steam pressure. It will be seen that if the steam reached full pressure in the steam cylinder at the moment the stroke started, as is customary and proper in power-engine practice, there would be practically double pressure on all the reciprocating parts and on the engine frame at this point, at which the velocity of the piston for a given amount of crank travel is very slow, so that this excessive pressure would come at a time to produce the least useful and the most frictional effect.

Inspection of the diagram, Fig. 73, will show that the engine builder

has prevented this in part by delaying the admission of live steam so that it does not reach full pressure until after the piston has moved an appreciable distance, by which time the pressure of air in the clearance space is considerably diminished by re-expansion. For this reason the combined net pressure diagram of air and steam cylinders (Figs. 92 and 93) instead of showing a sharp "spike" on the left-hand end of the diagram, as it would if steam were admitted to full pressure at the beginning of the stroke, shows only a considerable "hump." The practice in the case of the low-pressure diagram of the same set (Fig. 75) is even better in this respect, for it will be seen that in this case the piston has traveled the whole distance necessary to permit complete re-expansion of the air before steam reaches full receiver pressure in the cylinder, and if a combined diagram were made for these cylinders the hump at the left, shown in Figs. 93, 94 and 95, would not appear.

Following through this same idea these builders eliminate any compression whatever, both in the high-pressure and low-pressure cylinders. In fact, there is nothing in either diagram to show that the steam first admitted at the beginning of the stroke may not blow through into the exhaust. It is not possible to say from the indicator diagram that it does so, and the care and good judgment of the builders make it unlikely, at the same time so considerable an economy of steam may be effected by very little compression, and with such a slight increase in pressure, that I consider a small amount of compression desirable both for the steam it saves and to make it absolutely certain that live steam does not blow through into the exhaust at the beginning of the stroke.

It will be noted that in this diagram (Fig. 75) and also to a less extent in Fig. 73, the exhaust of the steam is extremely slow. The exhaust valve does not open at all until the end of the stroke is reached, and the steam consequently has little time to leave the cylinder while the engine is turning the center. The result is the sharp "toe" at the exhaust end of the diagram, which in my judgment should come down as shown in dotted lines, very materially increasing the area of the diagram without any ill effect.

Turning now to the Southwark engine cards shown in Fig. 101 we see practiced the exact opposite of that of the Tod Company in these particulars. The compression pressure rises to nearly half the receiver pressure and admission is so early that full receiver pressure is reached at the very beginning of the stroke.

On the other hand, the exhaust is early, so that full vacuum is reached almost at the very beginning of the exhaust stroke, as it should.

If combined net pressure diagrams were made of this set of air

and steam cards there would be found a "spike" of pressure at the beginning of each stroke which would just about double the total pressure on all the running gear and the engine frame for a brief instant of time at which it could deliver no useful work, owing to the low angle of the crank at that position, but in which it could greatly stress all the running gear and the frame of the engine itself and produce excessive wear if not an absolute hammering down of the brasses. Cases are on record in which certain engines of the walking-beam type broke their frames or pedestal caps repeatedly as long as the steam valves were set to give "lead"; that is, to give full pressure of steam at the beginning of the stroke, but which quieted down and ran without further difficulty when admission was delayed to compensate for the re-expansion in the air cylinders.

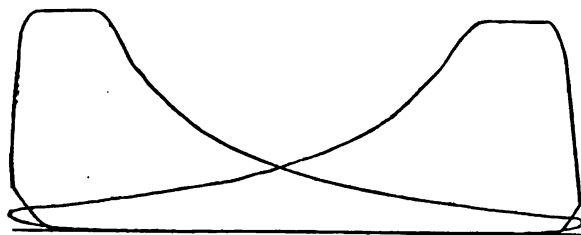


Fig. 102. Steam cards taken from Mesta long cross-head blowing engine.

It will be seen, therefore, that the practice of the William Tod Company and of the Southwark Company is at the two opposite extremes in this respect. The Tod Company uses no compression and delayed admission, the Southwark uses heavy compression and early admission.

I am able, through the kindness of the Mesta Machine Company of Pittsburgh, to present a pair of cards taken from one of their long cross-head blowing engines which seems to me to embrace the best practice in both respects. There is enough compression to reduce the total steam consumption appreciably, as can be judged by noting the percentage of the stroke still remaining to be made when compression begins; and then delays the admission sufficiently to allow full time for the re-expansion of the air in the clearance space.

In my judgment these cards are illustrative of the practice which should be followed by every blowing-engine operator in setting the valves on his blowing engine. It will be noticed that the early closing of the exhaust valve has its complement in the sufficiently early opening of these valves to prevent any loss of area by failure of the steam to exhaust promptly.

In general it may be said that the blowing engine should be indi-

cated at intervals of a few months to prevent or correct the multifarious misadjustments which can arise from many causes, many of which lead to waste of steam and others to excessive stresses similar to those I have described and worse.

At plants where economy of steam is not a prime consideration the hideousness of the steam practice which may prevail without preventing the operation of the plant is beyond belief by those who have not seen it. There is probably no field about the plant where so small an investment of time and trouble will pay so great a return in steam economy and repair expenses avoided.

The Turbo blower. — Within the last ten years the general introduction of the steam turbine and the high efficiency to which it has attained have brought about a great development in centrifugal machinery. It was formerly supposed that centrifugal fans were of no value for pressures above 1 lb. per square inch, and they were seldom or never compounded by putting two fans in series so as to increase the pressure they could attain. Instead, if a pressure of more than a few ounces was desired, the tendency was to pass to the use of the positive pressure blower.

The French engineer Rateau deserves the credit for working out into practical shape the use of the series fan capable of blowing pressures suitable for blast-furnaces. He introduced several of these machines in Europe about ten years ago.

Blast pressures in Europe are commonly not so high as those in this country, so these blowers were not suitable for American conditions. Moreover, it has been found to be universally the case that when a prime mover was introduced from Europe into America it had to be redesigned to meet American ideas and American conditions. This has been the case with the turbo blower. The first of these machines in this country was built by the General Electric Company for the Oxford furnace of the Empire Iron & Steel Company, and was started in 1910. A twin machine was started a few months later at the furnace of the Northern Iron Company at Port Henry, N. Y. Probably the largest single installation of these machines to date is that of the Iroquois Iron Company at Chicago, where the sole blowing power for two furnaces consists of three turbos with a capacity of 40,000 cu. ft. per minute each to a pressure of 30 lb.

More recently the Southwark Foundry & Machine Company has introduced the Rateau style of turbine into this country, and has already built several of them.

The Westinghouse Machine Company has as yet built no multistage turbine, but has built some single-stage machines for a pressure of 5 to 7 lb., these not being used in the iron industry, but under similar conditions in other industries.

The theory of the turbo blower is extremely simple. Air is admitted around the shaft, caught by the rapidly revolving vanes, or blades, of the fan, and has imparted to it a high velocity. This velocity is transformed into pressure, and the method by which this may best be done is a subject of some dispute among the designers of this class of machinery. The pressure obtainable in any one stage is limited by the speed which may be attained by the fan, and this is virtually the speed at which it is safe against the influence of centrifugal force.

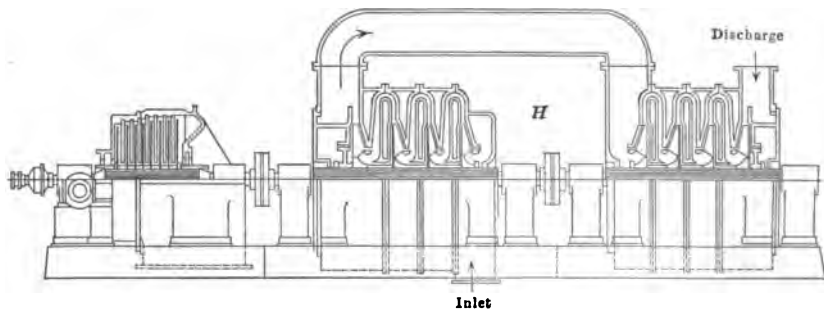


Fig. 103. Southwark Rateau turbo blower.

The discharge from one fan is led around through an annular port in the casing to the center of the next, which increases its pressure by a similar amount, and then to a third, and so on.

The number of stages to be used is not definitely settled. The Rateau blowers use eight, the first General Electric blower used six, but in the more recent types of construction the latter company have diminished the number of fans in series to three by increasing the speed.

The pressure increases more rapidly in the later stages than in the earlier ones because the density is increased by the increasing pressure.

The work put upon the air in compressing it heats it exactly as it does in a piston-blowing engine, but to a greater extent because the efficiency of the operation is lower with greater losses of energy in eddy currents, etc., which are eventually converted back into heat. The casings are therefore cored out hollow and cooled by water circulation to keep down the temperature of the air.

The Southwark turbo blower. — The internal construction of the Rateau machine as built by the Southwark Company is shown in Fig. 103. The U-shaped discharge passages by which the air discharged from one fan is delivered into the central aperture of the next are clearly shown. In this turbine there are fans or impellers in two groups of four each, the inlet of the first group being next to the cen-

tral bearing between the two sets. The air then progresses to the left and is discharged into a receiver pipe which carries it over into the inlet of the second group next to the inside bearing, and it then progresses outwardly through this group to the discharge at its right-hand end. In this way the end thrusts against the two sets of impellers are balanced against one another so as to throw as little work as possible on the thrust bearing.



Fig. 104. Steam end governing apparatus and thrust bearing adjustment, Rateau turbo blower.

The turbine which drives the blower is shown in half-section at the extreme left. The shafts for the turbine and for the two sections of the blower are all separate, and coupled together by flange couplings to permit an absolute alignment of each shaft in its own bearings. The shaft is located endwise by a thrust bearing at the left-hand end of the turbine shown in Fig. 104. This thrust bearing is capable of being moved and can be adjusted by a hand-wheel and screw to secure

proper clearance in operation. The general arrangement of this machine is well shown by Figs. 105 and 106.

The details of the design of the impeller, casings, etc., are highly technical matters in which mathematical theory and elaborate experi-

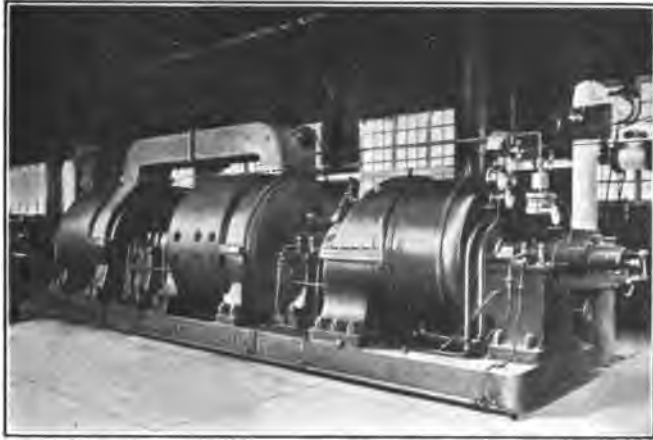


Fig. 105. Southwark Rateau turbo blowers.

mentation must go hand in hand to get the best results. To the great majority of users the only question of importance is how much steam is required to deliver a given quantity of blast at a certain pres-



Fig. 106. Southwark Rateau turbo blower.

sure, and the details of the methods by which the guaranteed results are obtained is a matter of indifference to them and I make no attempt to treat of these matters, because it seems to me outside the field of the present work.

The turbo blower is of course entirely valveless, and it therefore escapes the troubles of valve design and operation which I have briefly described in connection with reciprocating engines. It is also entirely without anything comparable to the piston displacement of the reciprocating blowing engine. That is, it has no metering effect, and its speed is accordingly no gage whatever of the quantity of wind it is delivering under given conditions. It is the function of a blower or centrifugal pumping apparatus of any kind to produce pressure and the flow which results is proportional to the difference maintained between the pressure at the discharge of the apparatus and the pressure in the vessel into which it discharges. If a reciprocating blowing engine, running at a certain speed, delivered the desired amount of air to a furnace at say 15 lb. pressure, and if the resistance of the stock in the blast furnace suddenly fell so as to let the pressure drop down to 14 lb., it would make little or no difference in the quantity of wind delivered by the engine, but with the turbo blower it would make an enormous difference, because it would endeavor to maintain the same discharge pressure, and with the pressure difference between this and the resistance of the furnace increased by the drop in the latter, the flow would be greatly augmented. For this reason the turbo blower requires a governing device capable of controlling the quantity of air passing through it.

In the Rateau system the well-known principle of the Venturi meter is used. In this an inlet pipe is provided which has a relatively small throat approached by a gradual taper and followed by an expanding taper to the normal diameter of the pipe. The difference in the velocity of the air at this throat and in the large area behind it, give rise to a difference in pressure at these points which depends upon the velocity of the flow, and by measuring the pressure with a differential gauge the flow can be accurately determined and controlled. The arrangement is shown diagrammatically by Fig. 107. The partial vacuum at the throat of the Venturi meter is maintained constant by means of a relay working on the steam governor of the turbine. If the flow increases the vacuum in the throat of the Venturi tube increases, and this acting through the relay cylinder operates on the steam valve of the turbine and reduces its speed, which in turn reduces the difference in pressure maintained by the blower, until the quantity of air flowing through it is reduced to the amount desired. A centrifugal governor is interconnected with the same system so as to close the steam valve entirely in case of excessive speed.

The General Electric blower. — The principle of this blower is the same as that of the Rateau, but the number of impellers used is smaller, and the whole of the blower is built in one body, without the feature of balancing by having the flow from the two half sections of the

impeller in opposite directions. This produces a shorter and more compact machine. This blower is shown by Figs. 108, 109, 110, 111 and 112, taken from a paper on the "Turbo Blower" presented by Mr. Richard H. Rice, of the General Electric Company, before the American Institute of Mining Engineers, and published in their Bulletin for May, 1914.

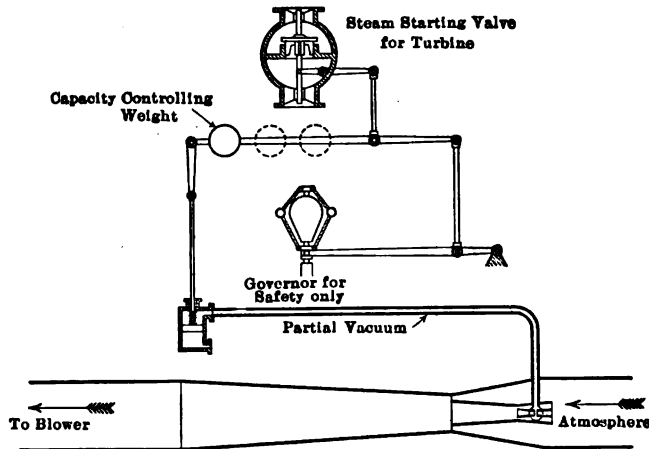


Fig. 107. Method of controlling capacity of Rateau turbo blowers.

The governing device of this machine is on a somewhat different principle from that of the Rateau; it is shown by Fig. 108. The inlet pipe ends in a large inverted cone in which a circular diaphragm is suspended from a scale beam overhead. It is obvious that the area of the annular space between the diaphragm and the walls of the cone will vary with the location vertically of the diaphragm, and that the flow of the incoming air up past this diaphragm will have a tendency varying with the velocity of the air through the annular space, to lift the latter diaphragm and the governing is done by this varying lift. Thus while a different mechanism is used, it produces about the same results as the Venturi tube.

If the pressure required by the furnace increases so as to decrease the flow of air under the speed at which the turbine is running, the diaphragm promptly drops down, carrying with it the beam which operates on the steam valves, and though a relay this admits more steam and increases the speed of the turbine until the flow of air is restored to the normal. In this turbine also a centrifugal governor is provided to prevent excessive increase in speed.

The advantages of the turbo blower are its small size, its entire freedom from reciprocating parts, and consequent ability to dispense with any but a light foundation, the small number of moving parts,

there being in effect but one, and its ability to dispense with lubricating oil both in the steam and air ends. Great advantages are claimed for it also in the absolute steadiness of the blast which it produces, and the freedom from pulsation which results from a continuous discharge.

In the paper by Mr. Rice above mentioned he describes researches which prove the absence of vibrations from blast, compressed with the turbo blower, and their presence with reciprocating blowing engines,

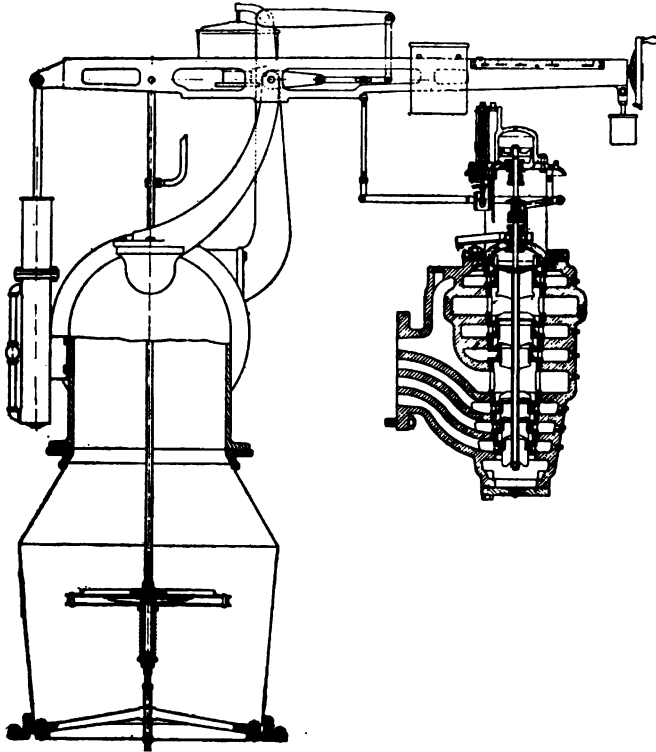


Fig. 108. Constant volume governor for centrifugal compressors.

but whether this absence may be translated into dollars and cents of advantages in operation is a matter concerning which no proof has as yet been offered and concerning which I confess to a considerable degree of skepticism.

It is claimed without hesitation that these blowers on account of the steadiness of their action, etc., enable a furnace to produce less flue dust and to make iron with less fuel than can be done with any other type of blowing machinery, but no definite data on this subject have been offered to support this contention, which also seems to me doubtful.

Fine points of this kind are always exceedingly difficult to prove in an operation of such magnitude as the blast-furnace, and the situa-

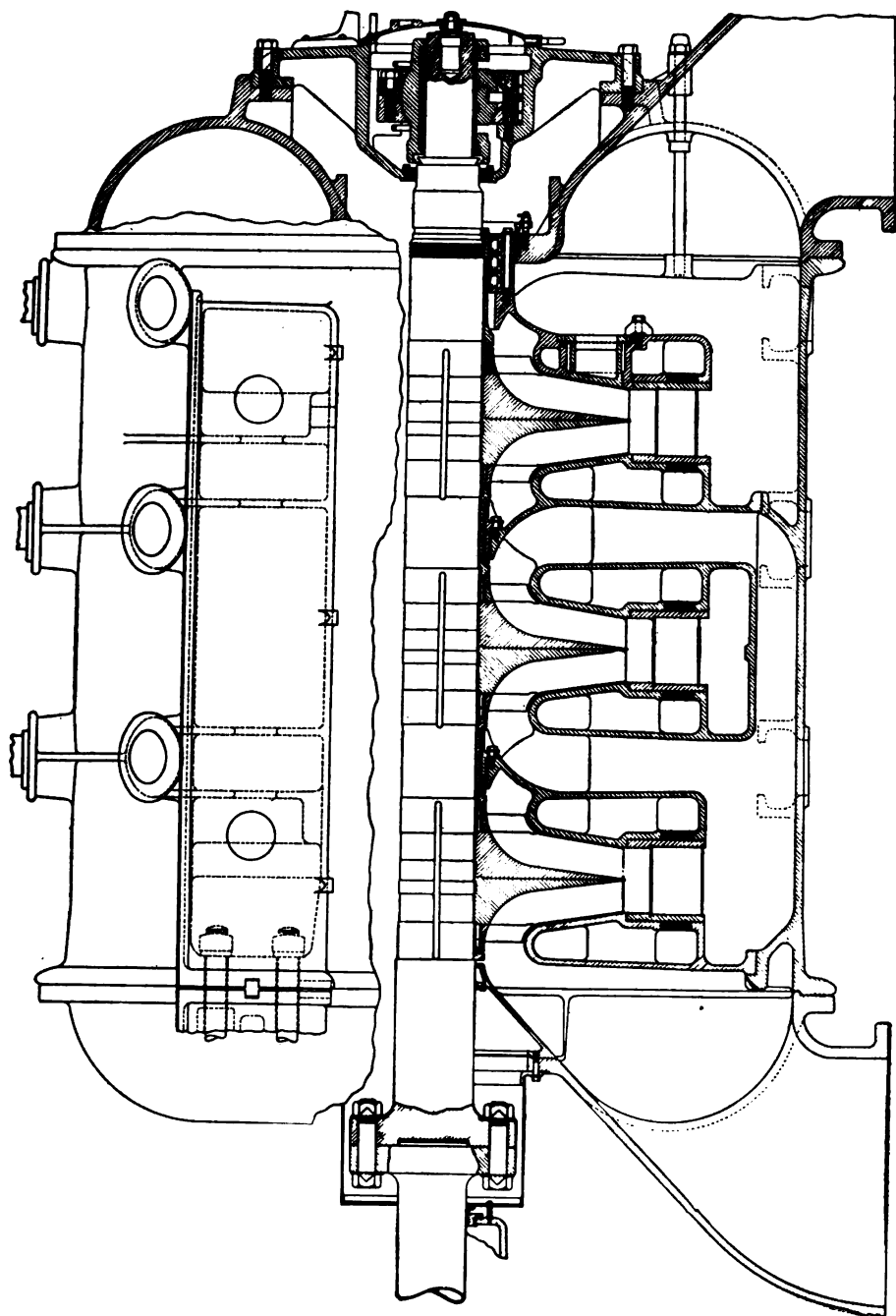


Fig. 109. Three-stage General Electric turbo blower partly in section.

tion is complicated by the fact that the turbines have in the nature of things, in many places at least, replaced obsolete blowing engine installed under bad conditions and therefore likely to be drawing steam

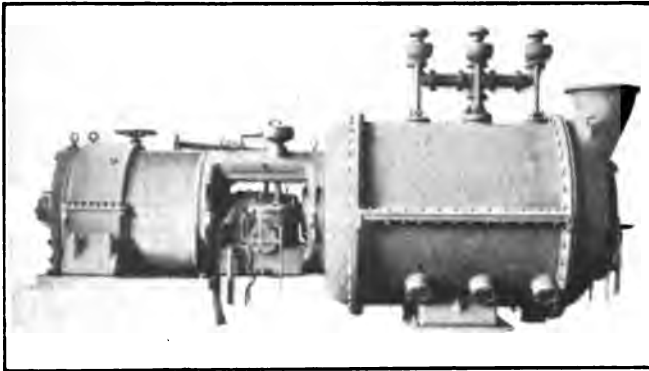


Fig. 110. Centrifugal compressor rated Type *T* — 3 — 25,000 — 15/30 — 3000/3800 driven by a 2000/3400 condensing Curtis steam turbine.

into their inlet and discharging it into the furnace along with the air, with consequent detriment to fuel economy. Moreover, these engines being old and uneconomical, and being presumably of the low-speed variety, they gave greater pulsation to the blast than more modern and high speed engines. It is therefore extremely doubtful whether the



Fig. 111. *T*—3—35, 000-15/30—2500/3250 *F* centrifugal compressor direct connected to 2900 H.P. Curtis steam turbine.

mere fact that certain advantages are found where the turbo blower is used, which were not found before its introduction, is due solely to the type of blower introduced, or whether they would not have been obtained equally well with any other type of good modern blower.

Much is claimed also for the accuracy of calibration of the air-measuring apparatus of these machines, and in a paper by Mr. S. G. Valentine, read at the February, 1914, meeting of the American Institute of Mining Engineers, and published in the *Transactions* for that year, he gives the results of his experience in the use of one of these blowers on a furnace which bear upon this point. Among other data

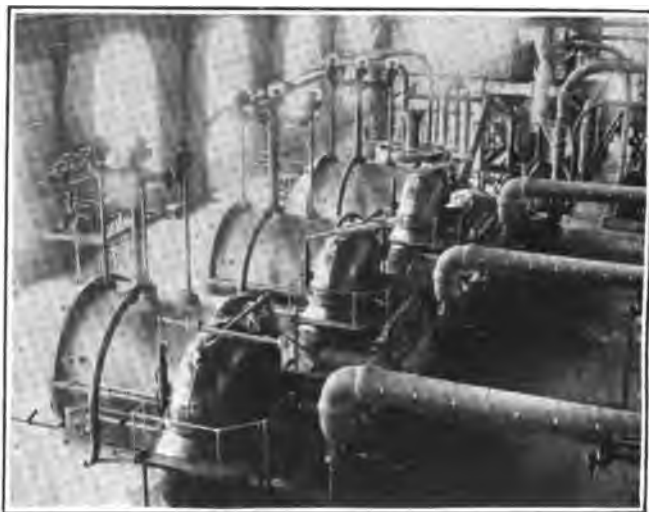


Fig. 112. Three type T—3—40,000—15/30—2500/3250 R. P. M. air compressors driven by 2900/5200 H.P. Curtis steam turbines installed at Iroquois Iron Company, Chicago, Ill., for blowing 500-ton blast furnaces.

he states that only 41 cu. ft. of air were required to burn a pound of coke based on the calibration of the air-measuring apparatus of the turbo blower. We shall subsequently see that about 63 ft. are required theoretically for this purpose without any loss by leakage, not only in the engine but around the stoves, the tuyere and elsewhere, and if only 41 ft. are used then one-third of all the fuel charged is being dissolved by direct deduction in the upper regions of the furnace and never reaches the tuyeres at all.

This hypothesis does not agree with the relative low fuel consumption reported by Mr. Valentine of about 2150 lb. of coke on an ore mixture consisting largely of magnetite which required a large amount of heat in the hearth, and, in fact, Mr. Valentine admits that his figures, based on the analysis of the top gases and carbon burned, differ from the calibration figures of the turbo blower by about 10 per cent.

I have information concerning practice in which the solution loss is likely to be much higher than it is in Mr. Valentine's practice, and

in spite of this the actual quantity of wind per pound of coke figured from the analysis of the top gases and the actual coke burned at a number of furnaces for a long period of time was over 51 cu. ft., or more than 25 per cent. in excess of that shown by Mr. Valentine's figures.

I have recently been advised by Prof. J. W. Richards, of Lehigh University, that he has gone over the data given by Mr. Valentine by two different methods and that both show clearly that the actual air delivered by this turbo blower must have been 15 per cent. greater than the calibration of the machine indicated, and making this correction it would seem that the correct displacement of the turbo only corresponds to about 3 per cent. more air delivered than the piston displacement of the antiquated engines it replaced. This is probably not altogether correct, but it does seem to be established by these data that the calibration of this turbo is decidedly incorrect and that any claims made for superior economy based on these results are a structure on a foundation of sand which will not fare well at the hands of discriminating criticism.

Considering the extremely elusive nature of air and the possibility of error in measurements of its velocity, due to the fact that this velocity at points quite close together may vary very widely, I am led to the conclusion that the calibration of these machines is not yet on a basis of such complete reliability as their manufacturers seem to believe.

The subject as a whole is a new one, and the number of those who have had an opportunity to handle turbo blowers is very limited, the writer not being among the number. It is therefore not possible at this time to say the last word on this or many other details of this subject.

The disadvantages of the turbo blower. — *I. Pulsation of discharge.* — Under certain conditions of operation at considerably less than the rated capacity of these machines, they are liable to a very disagreeable pulsation of the discharge, the theory of which I do not completely understand, though I believe it has been worked out mathematically. It seems to be due, however, to the fact that the volume is too small to maintain the delivery velocity necessary to overcome the pressure over the whole area of discharge, continuously, and the discharge therefore breaks and a backflow from the discharge pipe into the turbine casing takes place at short intervals, producing this pulsation. It is claimed to be overcome in the later types of these engines by the introduction of a butterfly throttle valve in the inlet pipe above the diaphragm.

II. Inefficiency. — The efficiency claimed for these machines by their builders under best conditions is 70 per cent., and of course this

falls off on both sides of the maximum along the characteristic curve of practically all centrifugal pumping machinery.

The diagram factor of the air card from a well-designed blowing engine as a whole is about 95 per cent., and the mechanical efficiency of the engine as a whole, as I have previously stated, should be about 92 per cent. By diagram factor is meant the ratio of the actual diagram produced by a given engine under a given discharge of pressure to the theoretical indicator card with an adiabatic compression for the same pressure. The product of these two is about $87\frac{1}{2}$ per cent., the difference between this and 70, or 25 per cent., is the handicap which the turbo blower must overcome to equal the performance of the reciprocating blowing engine.

Turbines have been brought to a very high state of perfection, particularly in very large units, such as are used in electric generating stations. But a turbine of, say, 3000 h.p., with an efficiency of 70 per cent. in the blower end, which would deliver 2100 air-h.p., can certainly not do 25 per cent. better in steam consumption than a steam engine properly designed and running with the conditions of boiler pressure, superheat, and vacuum which are admittedly indispensable to the economy of the turbine.

If it be impossible for the turbine to do 25 per cent. better than the reciprocating engine under these conditions, then obviously the superior efficiency of the turbine will not offset the low efficiency of the blowing end, and the turbo blower as a whole will be a less economical unit than the reciprocating steam engine.

The steam expert of one large and extremely well-managed company has publicly expressed a doubt as to whether the turbo blower could get along with as little steam as the reciprocating engine, his company having both reciprocating engines and a turbo blower in the same building and operating under identically the same conditions.

III. Failures. — There have been several wrecks of turbo blowers in this country, but these apparently have been due to defects in the design of new and larger units than had before been attempted, rather than to any inherent defect in the principles involved. This we have long since learned is the price which must be paid in the development of new equipment, and must therefore not militate unduly against the turbo. At the same time, it cannot be denied that turbines in other service have more than once "gone through themselves," to use the expressive phrase of the operator, with consequences so disastrous as to leave little of the structure of any value, even for repair purposes. Before the turbo blower can establish the supremacy towards which its builders are casting their eyes, it must establish a high degree of immunity from accidents, and also an economy not only eclipsing that of the best reciprocating steam engines, but rivaling that of the gas

engine, which increasingly, as time goes on, must become a powerful competitor in blowing machinery.

The condenser. — The auxiliaries of the steam plant at a blast-furnace do not differ from those of any other steam plant of similar size and character, and for that reason it is not necessary to discuss most of them here, but the condenser is important enough to deserve some attention.

These for steam engines are of two types, the direct contact or jet condenser, and the surface condenser. Surface condensers are high in first cost and having an enormous number of packed joints are difficult

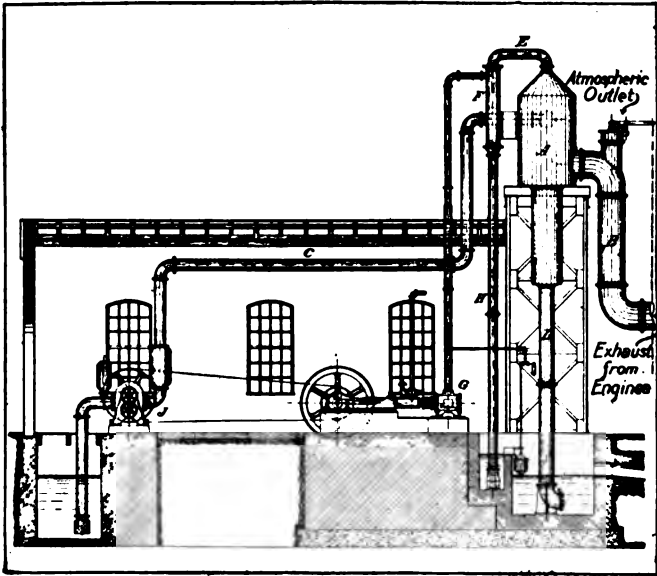


Fig. 113. Weiss condenser.

of maintenance for continuous operation. Moreover, the water available at blast-furnaces is not always of such character as to enable them to be kept as clean as they should be for best results, and when foul they soon lose their efficiency and the vacuum drops. For this reason when reciprocating blowing engines are used the elevated syphon condenser, working on the counter-current principle, and with positive means for removing the air, is very generally preferred.

The first of these brought into use was the Weiss, introduced by the Southwark Machine Company, shown by Fig. 113. This is of the elevated type with a vertical tail pipe about 35 feet long, high enough, in other words, to carry out the condensing water and water of condensation without pumping, against any vacuum which the condenser may produce. The air is taken off from the condenser by a dry-air

pump, *G* in the illustration, the condenser being designed to discharge the air after it has received the maximum cooling possible, so as to make its density at this low pressure as high as possible and enable the air pump to handle it to the best advantage. The air-pump engine

drives by belt or gear drive a rotary pump, known as the Bibus pump, which supplies the water for the condenser. The Bibus pump is used on account of its high efficiency, but owing to its gearing, etc., this pump is not as well adapted to run submerged as is a plain centrifugal pump, and as condenser pumps in the nature of things are extremely likely to be submerged from time to time, I personally prefer the simpler if somewhat less efficient centrifugal machine which can run submerged indefinitely.

Several condensers of the same general style as the Weiss are now on the market, of which one of the best and most favorably known is the Helander (Fig. 114), designed by the late A. H. Helander, formerly chief engineer of the Mesta Machine Company, afterward vice-president of the William Tod Company. This condenser dispenses with the supporting tower used by the Weiss, the tail pipe of the condenser itself being made strong and stiff enough to support it. The air is taken off at the high point of the condenser body, as in the Weiss, different types of apparatus being used to pump it out.



Fig. 114. Mesta Helander barometric condenser.

In some installations a steam jet or modified exhauster has been used whose steam economy is not very much lower than that of a mechanical pump, which

is low in first cost, and completely eliminates moving parts. In other cases a crank and flywheel vacuum pump is used as in the Weiss. Water is generally supplied by a centrifugal pump driven either by a motor or by a small direct-connected steam turbine.

In blowing engine plants one condenser is generally installed for several engines, and this system has much to commend it, at the same time if steam for many units is to be condensed, the distance through

which the exhaust has to be carried to the condenser becomes great and the piping large and expensive, while the vacuum realized on the further engine is probably never as good by an appreciable amount as in the nearer engines, so that this system must not be carried to

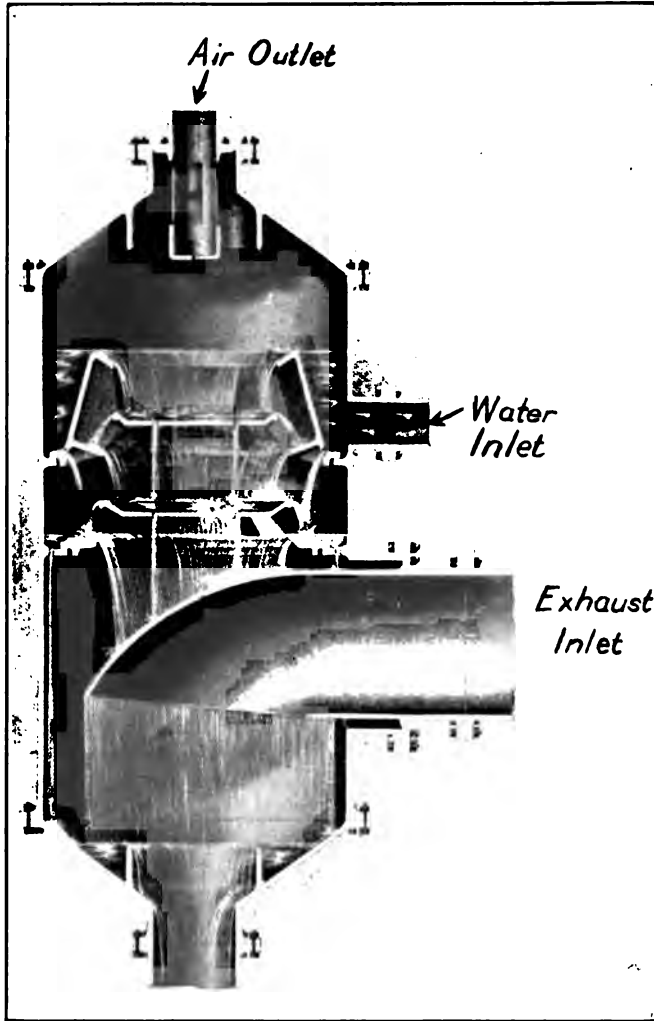


Fig. 115. Vertical cross-section of Helander condenser vessel.

extremes, especially as the high cost of the exhaust piping in a large installation would go far to pay for additional condensers. Neither must it be forgotten that several units of this kind have the advantage of greater flexibility and more freedom from general interruption than a single large unit.

For turbines the barometric condenser is sometimes used, but to get the best results these machines require vacua which measured as absolute pressures are only from a half to a third of those used with steam engines, therefore it is highly desirable to have the exhaust connection extremely short and very large so as to avoid both friction losses and leaks. For these reasons the condenser for the turbine is, in the best practice, placed immediately beneath it and in some cases forms the base upon which the turbine rests. For this service either a surface condenser is used or some sort of jet condenser with water-discharge, as well as dry-air pumps. The former is particularly desirable with turbines for the reason that their exhaust contains no oil and may be used for boiler feed without treatment, and for the high vacua desired in this service it has the advantage of not introducing any air dissolved in the condensing water, which is an important factor under these conditions.

As a result of these considerations new types of jet condensers have been invented and new designs of surface condensers brought out so that condensers as a whole have received a vast development in recent years. In relation to blowing power for furnaces, however, these conditions are not sufficiently important to justify more extensive treatment here.

Combination of turbine and reciprocating engine. — There is an application of the turbo blower to blowing engines of which no actual installation has as yet been made, but the possibilities of which have been figured out on the basis of actual practice, and specifications prepared for such an installation.

This is a combination with existing blowing engines of the turbo blower driven by a low-pressure turbine. The turbo blower is not designed to blow the full pressure required for the furnace, but only to do about one-half the work of compression, supplying the air under this partial pressure to the air cylinders on the existing blowing engines.

The advantage of this combination is that the turbine is a more efficient motor for pressures below atmospheric than the steam engine, particularly where high vacua are obtainable, and the turbo blower, while not more economical for low pressure than a good piston blower, is relatively more economical for low pressures of 6 or 7 lb. than it is for pressures of 15 lb. and upward, not because the turbo itself has a higher efficiency at the lower pressures, but because the friction of the large cylinders required for reciprocating blowers, unless they are most carefully designed, reduces the mechanical efficiency of that type of machine at low pressures, so that it is doubtful whether they are as economical below 6 lb. as are rotary blowers or perhaps turbo blowers, therefore the rotary unit as a whole is more economical than a reciprocating one for very low pressures. It is also much lower in first cost,

and by combining the two types of machines and using each for the range of pressures for which it is best adapted, we obtain the highest efficiency with the lowest first cost. This is particularly true where existing installations are either uneconomical, unable to blow the pressure required, or unable to furnish the volume required.

By putting a turbine and condenser on the exhaust of a non-condensing engine we can recover a horse-power for about 30 to 35 lb. of steam, depending on the vacuum available. This power applied to a turbo will compress the quantity of air required to a pressure in ordinary cases of 5 to 7 lb. This increases the density of the air and therefore increases the capacity of the air cylinders of the reciprocating engines, and also obviously raises the pressure to which they can compress the air by at least the amount of this precompression.

The turbo blower will compress air to a pressure of $6\frac{1}{2}$ or 7 lb. in a single stage; therefore, in ordinary cases only a single-stage unit will be required in applications under this system.

Both the reciprocating engine and the turbo blower labor under certain disadvantages when used singly which are eliminated when they are used in combination, thus the turbo blower alone must have stages enough to blow the maximum power required, for instance, 30 lb., even though 15 only will be required 99 per cent. of the time. Similarly the air cylinder of the reciprocating engine must be large enough for the maximum volume of air to be handled, even though this be required only occasionally. The turbo blower, on the other hand, can supply any increase in quantity of air desired within reason, without any change in its construction, while the blowing engine can compress to any pressure within reason without any change in its construction.

By combining these two units we obtain the volume capacity of the one and the pressure capacity of the other without the need of excessive size in one case, or multiple stages in the other. This arrangement has also the great advantage of retaining the metering effect of the piston of reciprocating engines, which is certainly more positive than the systems of volume governing so far applied to the turbo blower.

In the combined unit the question of governing the turbo practically takes care of itself, since the quantity of steam exhausted by the reciprocating engine controls the speed of the turbo, and this steam must depend upon the volume of air blown and the pressure to which it is raised. If the blast pressure required increases, the tendency of the reciprocating engine is to slow down slightly and so slightly to decrease its discharge while the increased quantity of steam which it exhausts tends to increase the speed of the turbine and so to increase the pressure at which the turbo blower discharges, thus making up by an

increase in density for any decrease in displacement of the reciprocating engine.

In the actual case for which specifications were prepared, there were three standard long cross-head blowing engines, two with good steam cylinders, the other with a poor steam cylinder, all non-condensing. The owners had obtained bids on a single low-pressure unit to take the exhaust from one of these engines and run condensing, letting one of the high-pressure engines run condensing with the other standing as a spare.

It was easy to show that on the basis of the guaranteed figures of the turbo blower manufacturers a single turbo blower could be installed which would supply the two good existing high-pressure engines with air compressed to $6\frac{1}{2}$ lb., and this increase in density, with a slight and entirely permissible increase in speed, would have made the weight of air discharged by these engines the same as that now discharged by all three. The exhaust from both of these would have gone into the low-pressure turbine, and from that into the condenser, and would have been sufficient with any ordinary vacuum to drive the turbo blower at a speed which would enable it to supply precompressed air to both reciprocating engines. The third engine would have stood as a spare. The air cylinder heads of the blowing engines would have required to be closed in so that they could receive this air under pressure. A large inward-opening check was to be provided in the pipe carrying the precompressed air so that if anything happened to the turbo blower it could instantly be shut down and the reciprocating engines would then get their air supply from the atmosphere. This would have given the furnace two-thirds wind until the third engine could be started up, which would be only a matter of a few minutes. Finally it was shown that this equipment could be installed complete for a considerably smaller sum than would be required for the low-pressure unit, and that its steam consumption would be smaller than that on the other plan by several thousand pounds per hour.

This possible installation is set forth here because of the advantages which I believe it to have for such cases. It may also be said that the installation above described, while not installed as yet, was not rejected by the owners on account of any defect in the system, but only because they decided not to install additional blowing power at that time.

The gas-driven blowing engine. — It is now more than half a century ago that Otto first built internal combustion engines using the four-stroke cycle, and the economy of these engines was early recognized as being far superior to that of the steam engine in thermal units required. Before the days of the universal use of gasoline, gas was the only fuel used in such engines, and the difficulty of making suitable producer gas for them stood in the way of their earlier introduction.

In the case, however, of blowing engines for blast furnaces, which are in one sense only gigantic gas producers, the advantages of using the gas they supply directly in the engine cylinders are obvious. The first suggestion to carry out this plan was made in 1876 by Mr. Frank Firmstone, then manager of the Glendon Iron Works, to Mr. P. L. Weimer, of Lebanon, an engine builder of some note, but nothing was done in the way of carrying it out for nearly twenty years, when in 1895 Mr. B. H. Thwaites in England installed a small gas engine and operated it continuously for a considerable period on blast-furnace gas.

The idea was then taken up by German and Belgian engineers and to them is due the credit for overcoming the enormous technical, mechanical and financial difficulties involved in carrying this simple scheme into successful practice.

It was only after engines of this type had reached a high state of development in Europe that they were introduced into this country, a circumstance which has caused much shame to some good Americans, but I believe does not reflect as much discredit upon this country as has frequently been claimed, on account of differences in conditions unnoticed by casual observers.

These differences are financial and industrial rather than technical, and consist in the fact that in Europe capital can earn only a relatively small rate of interest and labor only a small rate of wages compared with what both command in this country, while raw materials, particularly coal, are scarce and dear in Europe and have in the past been ridiculously cheap in this country.

The saving to be made must be bought, as we shall presently see, at the price of enormous expenditures in capital and in high-priced skilled labor, while its value could only be measured in terms of the saving in coal, one of our cheapest commodities.

When these technical savings were reduced by the amount of the high labor cost required to make them, the interest which the balance would pay on the capital involved was often less than could be earned by that capital in increasing the producing capacity of the plant.

It is true that this view of the subject involves the use of coal which might be saved for future generations by the other system but this is a subject to follow which would take us far beyond the proper boundaries of this work and I shall not attempt to analyze it further than to suggest that, admitting the value of the "conservation" idea, it is proper to ask whether the saving of money, which represents value already created, may not be as justifiable as the saving of raw material which only has potential value.

Or to put the matter in different form, if the owner of a plant can make more interest on the capital invested by using more raw material

than is theoretically necessary, who is to compensate him for the loss he makes by following the opposite course?

On the other hand, this policy is capable of great abuse, and Americans, as a nation, have had in the past and to some extent have even yet a tendency to prodigality and to ignore savings of various kinds which they might make, more through mental inertia than through any more worthy motive.

It may be admitted that the policy of conserving capital at the expense of raw material has often been carried too far, and the gas engine may be such a case. I shall give at the end of this chapter an outline of the method by which this question may be settled on its merits in each individual case.

The difficulties to be overcome. — The conditions to be met, and the difficulties to be overcome in making the gas-blowing engine a success may be briefly stated as follows:

First: Blast-furnace gas as it comes from the furnace contains a vast quantity of fine and exceedingly abrasive dust which must be completely removed before it is introduced in the cylinders of the engine or the latter will soon be destroyed by wear.

Second: The gas engine is a prime mover with little or no overload capacity, and with an efficiency which diminishes very rapidly as its load drops off. The opposite condition prevails in the case of the steam engine, which has a very large overload capacity, and which maintains its economy well at loads very much smaller as well as much larger than its rated load. Therefore, when the blast pressure required by the furnace changes, the steam engine has no difficulty whatever in accommodating itself to the change, but the gas engine must either work at the disadvantage of an uneconomically light load normally, in order to be able to carry the heavier pressures when they arise, or else it must have special devices to enable it to compress less air when a high pressure is required, at the same time increasing its speed and power.

Third: The gas engine when it began to be developed for use for blast-furnace gas was very largely a single-cylinder, single-acting engine, which, with the four-stroke cycle, meant that it received but one working stroke in two revolutions. The reason for this limitation was that it was considered almost impossible to operate piston rods with their accompanying glands at the high pressures and high temperatures involved in this type of engine.

Fourth: Owing to the intermittent and rather complex nature of their cycle these engines were in the early days freakish, unreliable, uncertain, and difficult to operate to a degree which in the opinion of many American engineers debarred them from use, especially for blowing service.

Fifth: Owing to the operating difficulties just mentioned, and to the high repairs which went with them, the operating and maintenance cost was very high.

Sixth: The first cost of these engines, both for the engine proper, for foundation and for house, was and is even yet enormous, and as this first cost must be amortized at a relatively heavy rate on account of the rapid obsolescence and somewhat rapid deterioration of these engines, the fixed charges on them were very high.

Coming now to the solution of these problems and difficulties, the result desired has been achieved in each case by the same formula. A vast amount of technical work of the highest order, the endurance of a vast number of operating difficulties which resulted in deficient blast supply for the furnaces at frequent intervals of uncertain duration, and made the managers regret the day that the gas engine was born, but which led eventually to methods whereby these difficulties might be avoided or overcome, an enormous number of experiments, many of which in the nature of things were unsuccessful, and the expenditure of great sums of money for development.

The cleaning of the gas.—Great harm was done to the gas engine in its early days by the premature publication of the results of an experiment in using gas which had not been thoroughly cleaned. It was claimed that only primary cleaning was necessary, and that the fine dust left by this simply went into the cylinder and came out again without doing any harm. A few months' longer trial, however, soon showed that while most of the dust followed this course, enough of it adhered to the oily surfaces of the cylinder and piston rod to cause the rapid destruction of those parts, and it was then realized, once for all, that the gas must be cleaned, not only in primary washers, but must be scrubbed until the amount of dirt left in it was a negligible quantity. It is said that in present practice the gas passing into these cylinders is cleaner and more free of dust than the air we breathe.

This is not the place at which to deal with the question of gas cleaning, but it seems to be a fact that a positive and reliable solution of this problem, which could be guaranteed, was first obtained by the German engineer Theisen, and after the invention of his apparatus the development of gas-driven engines was much more rapid than before.

Adapting the engine to variable loads.—In Germany the method has largely been adopted of holding open the inlet valve during a greater or less portion of the compression stroke, and so, in fact, cutting down the capacity of the air cylinder when higher pressures were required than those for which the engine was designed. But in this country this plan seems not to have found favor, except with the Wm. Tod Co. of Youngstown, and in general the gas cylinders have been

made large enough to blow the maximum pressure normally required, any change from this being met by adjustment of quantity or quality of gas mixture and enduring the consequent loss of efficiency.

This is for the reason that when a furnace gets "tight" and the pressure goes up, it is frequently, if not generally an indication that it needs more air and if this be not supplied a scaffold is liable to form causing weeks or months of trouble.

Therefore the plan of reducing the volume of the blast in order to attain the increased pressure needed does not commend itself to furnace men; it is good for the engine, but likely to be very bad for the furnace.

Adapting the engines to run double acting with tandem cylinders. — The difficulties which prevented this development in the early days were those which came from the intense heat acquired by any surface of small curvature, such as a piston rod, unless it was water-cooled. The head and barrel of gas-engine cylinders have been water-cooled since the very beginning, but on account of the mechanical difficulties the early engines were made single acting and their pistons were not so cooled but made long and allowed to get their cooling effect from the barrel of the cylinder and from the air in the crank chamber. This, with the plain flat piston heads without projections, enabled them to run without getting so hot as to cause premature explosions.

When it became necessary to obtain more working strokes per cycle the trunk piston was discarded and the regular piston and piston rods of the standard engine substituted, except that these were both made hollow and water-cooled by flexible or trombone connections to the cross-head or to the rear end of the piston rod. This having been brought into successful practice, the next step was to add a tandem cylinder and run the piston rod through to its piston, and with the experience based on the previous work this was soon brought into successful operation also.

In the four-stroke cycle single-acting gas engine only one stroke in four is a working stroke instead of every one, as in the steam engine. Therefore by putting two double-acting cylinders tandem and having their working strokes alternate one with another two working strokes per revolution were obtained as in the steam engine. This resulted in an enormous reduction of the irregularities of power development and of turning moment, from which the early single-cylinder gas engine suffered.

Elimination of difficulties and uncertainties of operation. — This has been even more than the others a matter of patience and detailed attention to small and apparently unimportant points. The ignition system which was at one time under electrical control and with only one igniter per cylinder head, has now been made entirely mechanical

with two or more independent igniters per cylinder end, so that one will ignite the charge if the other fails. Pilot lights on each of these igniters show whether they are working or not and enable difficulties to be cured before shut downs from the failure of both can occur.

The type of design which has the strength to resist the heavy internal pressures due to the gas explosion, and at the same time is so free from inequalities as to avoid heating strains, and the cracking and failing of cylinder heads and pistons which come from that cause, has gradually been evolved. The system for supplying water for cooling the pistons and piston rods has been developed so that the formation of air and steam pockets is prevented, and the overheating and consequent cracking and premature ignition which arose from those causes are thereby avoided.

In this country the center crank construction has generally been discarded in favor of the overhung single crank because the latter requires only one main bearing and definite knowledge of its adjustment and condition and of the stresses upon it are obtainable, whereas when the center crank is used, two main bearings are required, the racking stresses which may be developed by the maladjustment of one of them are enormous and entirely impossible to determine. Nevertheless some of the most recent gas blowing engines built by the Mesta Machine Co. have returned to the center crank construction on the ground that a smaller and lighter crank gives the same strength and has less overhang.

The valves of the engines have been put in convenient and accessible locations so that they can be readily removed for examination or replacement, and at the same time so that dirt will not lodge upon their seats, with the consequent destruction of the latter.

All of these details and many more have been subjected to the most rigid, patient, and penetrating investigation, so that the causes which led to these difficulties have either been avoided altogether or their results have been overcome to the best advantage.

Expense of operating and maintenance. — The thorough cleaning of the gas eliminated at one stroke a great number of the operating difficulties of the gas engine, while hand in hand with this went the knowledge obtained by both designers and operators from the patient investigation and improvement of details described under the fourth heading, so that great plants of gas engines may now be seen running apparently with but little more attention and no more repairs than would be required by an equal number of steam engines of similar power.

The reduction of the gas engine to standard practice. — The gradual elimination of the experimental work required in the early days of gas engine development, and the fact that a number of reliable and

experienced engine builders have undertaken its manufacture under competitive conditions, have all tended to reduce the first cost of these engines, while the standardization of designs and better adaptation of the means to the end sought have lowered their rate of obsolescence so that the amortization period is longer and this in conjunction with the lower first cost has greatly reduced the overhead charges.

Type of gas engines. — Owing to the length necessary on account of their tandem cylinders and to the excessive stresses to which they are liable from the nature of their working cycle, gas engines in large sizes for the iron and steel industries have never been built except as horizontals, therefore the number of types is very much more limited than is the case with steam blowing engines.

The first installation of gas blowing engines on a large scale in this country was that of the Lackawanna Steel Company at Buffalo, which was started about 1903-04, and has been the bone of many bitter arguments pro and con on the whole gas engine situation and on the particular type of engine installed. These are two-stroke cycle engines built under the Koerting patents.

They have a single double-acting cylinder on each side and every alternate stroke is a working stroke exactly as in the steam engine, their gas and air being supplied them by large pumps driven by cranks on the ends of the main shaft, one of which supplies the gas, the other the air, not only for combustion, but also for scavenging the cylinder of the burnt gases from the last stroke. This is done by a "plug" of air which is driven through the cylinder behind the burnt gases and in front of the fresh charge, and to a great extent prevents the mixing of these, which would greatly reduce the efficiency.

No exhaust valve is used. The piston uncovers an annular port in the cylinder near the end of its stroke and the burnt gases and plug of scavenging air escape through this while it is uncovered. During the latter part of this interval the fresh charge is introduced into the rear end of the cylinder, but is prevented from escaping by the air plug.

This engine then, avoids the necessity of having two cylinders to make each stroke a working stroke and avoids the exhaust valves of the four-stroke cycle, but does so at the price of two large crank-driven pumps which have to raise the charge to higher pressures to force it into the cylinder than are necessary in the four-stroke cycle. In addition to this the air required merely for scavenging, must be handled and compressed. These engines after more than ten years of continuous service are still in regular operation and, although steam blowing engines are installed, they are held in reserve and the gas engines run by preference not only of the mechanical department, but also of the furnace manager, because they are not only more economical but require less attention and repairs than the steam engines.

The gas-cleaning installation at this plant is almost rudimentary as compared with more modern ones and the resulting gas much less clean, yet these engines are operating successfully with the original cylinders in some cases without even being bored out and lined, with some of the original piston rods, and almost all the original pistons.

These engines have horizontal gas cylinders and vertical air cylinders concerning which construction no more need be said than was said concerning the steam engine of that type, except that the high speed and great inertia of the reciprocating parts of the gas engine makes it even more unnecessary than in the steam engine, and it has not so far as I know been used in any other large installations of gas blowing engines in America.

Judged by the test of time and service this installation must be judged as great a success as an initial installation of any kind ever is. It was described in much detail by Mr. E. P. Coleman in Vol. XXXII of the *Transactions* of the American Society of Mechanical Engineers, in which excellent article the statement is made that these engines require about 18,500 B.t.u. per indicated horse-power in the air cylinders, an efficiency of 13.7 per cent.

Recent types of four-cycle engines at three-quarter load give about 22 per cent. efficiency at the shaft and reducing this by 10 per cent. we get 20 per cent. as the efficiency based on the indicated horse-power in the air cylinder or nearly one-half more than of the Koerting engines, so the reason for the exclusive use of the four-cycle type is not far to seek. At the same time these four-cycle engines represent a much more recent state of development than do the Lackawanna engines and it is claimed that the later examples of this Koerting type in Europe give far better results than do the earlier ones. Still it must be acknowledged that while many attempts have been made to improve the economy of the two-cycle engines for all uses and in all sizes none of these attempts have ever succeeded in putting it in the same class for economy as the four-cycle, and it may now probably be said with safety that there are fundamental obstacles to success in this endeavor, which will never be overcome.

Fig. 116 shows a gas blowing engine built by the William Tod Company with twin tandem gas cylinders on one side of the crankshaft and a blowing cylinder on the other side, driven by stretcher rods as described for the inside crank steam engine. This construction is no shorter than that of a straight tandem engine, and as the piston rods pass through the cylinder heads, and are supported by slides outside them in all cases, I do not fully understand the advantages of this construction, but it is in extensive use and seems to give good satisfaction.

Fig. 117 shows a similar design of engine built by the Allis-Chal-



Fig. 116. 42 and 80 x 60 gas blowing engine.

mers Company, and Fig. 118 shows one of the largest installations of gas blowing engines in this country, also built by the Allis-Chalmers Company.



Fig. 117. Allis-Chalmers 44 x 60 twin tandem gas engine with 60 x 60 air cylinders.

Fig. 119 shows in outline a straight tandem gas blowing engine built by the Mesta Machine Company with the crankshaft at one end, the blowing cylinder at the other, a design which I prefer to the inside crank type.

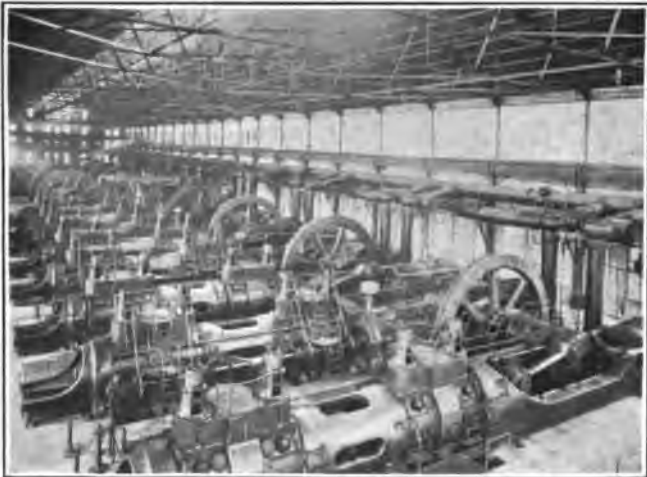


Fig. 118. Row of eight Allis-Chalmers gas blowing engines.

All these engines are of the four-stroke cycle, double-acting, double-tandem type with admission valves and exhaust valves all in the cen-

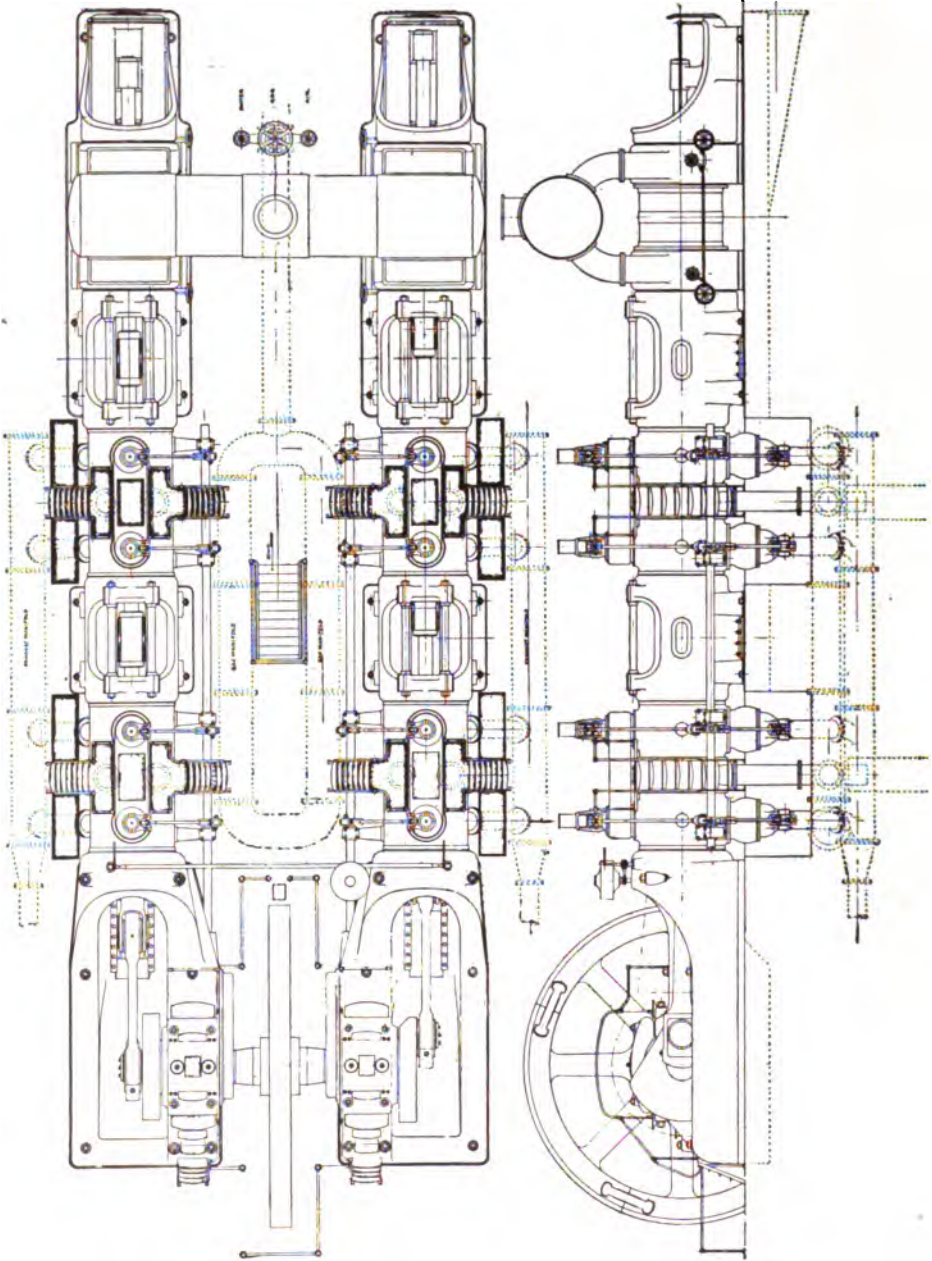


Fig. 119. Mesta gas blowing engine twin tandem arrangement.

tral vertical plane to give maximum accessibility without the necessity of removing cylinder heads and to avoid the formation of pockets in the cylinder heads.

The details of the designs differ but not very much more than the details of steam engines.

The air cylinders do not differ from those of steam engines except that the speeds at which they are required to run average higher and the valves must be designed to meet this condition.

The speeds of gas engines. — It is a remarkable fact that a number of builders of blowing engines should balk at the idea of running a steam-driven blowing engine more than 40 revolutions, yet regularly design and build gas engines of the same stroke to run from 70 to 85 revolutions, and the situation is made the more remarkable by the fact that the reciprocating parts of the gas engine are about 50 per cent. heavier than those of the steam blowing engine of similar capacity. This, with their high rotative speeds, double those of many steam engines, makes the inertia about six times as great as it is in the steam engine. The set of indicator cards from a gas-driven blowing engine, obtained through the kindness of the William Tod Company of Youngstown, and shown by Figs. 120, 121, and 122 (page 184) are from a 42 and 80 × 60 gas engine with a rated speed of 65 revolutions, with reciprocating parts weighing 94,500 lbs. for each side.

From these I have prepared the net pressure diagrams for a pair of gas cylinders and the corresponding air cylinder, shown in Fig. 123 (page 185). These have been reduced into a combined net pressure diagram of both sets of cylinders, shown in Fig. 124 (page 186), on which is drawn the line of inertia effect at 65 revolutions and in dotted lines the inertia effect at 60 revolutions.

In Fig. 125 (page 187) is shown the resultant of these combined air gas, and inertia diagrams at 65 revolutions. It will be seen that the equalization of power developed and power absorbed by this means is very good, but that the speed is, in this case, if anything a little too high, and that a better equalization would be obtained at 60 revolutions.

The stroke of this engine is 5 ft., that of the horizontal cross-compound, of which inertia and combined diagrams were presented earlier, was 6 ft., only 20 per cent. more. It seems remarkable that this engine should be run at a speed of 65 revolutions, while the rated speed of the steam engine was only 40 revolutions, although it would obviously do better work if its detailed proportions were right, at 55 revolutions, than it would at 40, with an increase in output of practically 40 per cent. and without any countervailing disadvantage.

I think the explanation is that the gas engine simply will not run properly at low speeds on account of the tremendous variations in pressure, and the reversals of stress consequent on them, so that engine

builders have been compelled to run them at a proper speed whether they would or not; while in the case of the steam engine the reversals of stress were so much less severe that the engine could endure them without the equalizing influence of the inertia effect, and the obvious advantages of higher speed have been ignored because the engine could get along without them.

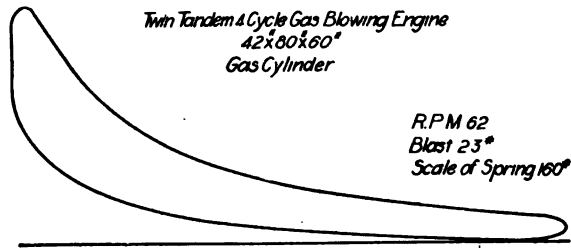


Fig. 120

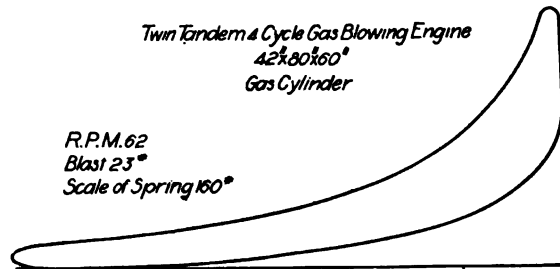


Fig. 121

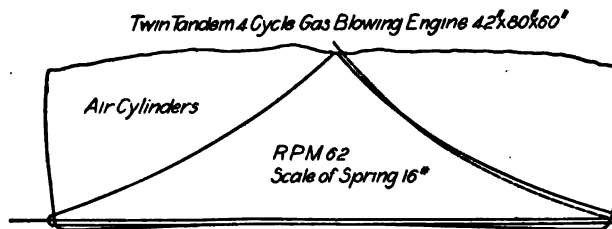


Fig. 122

Figs. 120-122. Tod gas engine cards.

It may be of interest also to point out here the "spike" of pressure due to the reëxpansion of the air in the clearance space which increases the total pressure on the running parts of the engine 15 or 20 per cent. above what it should be at the beginning of the stroke.

It would seem that by delaying the ignition very slightly the explosion line of the diagram could be made to slope forward by a very small amount so as to offset the pressure from the reëxpansion of the

clearance air and that this would not lessen the area of the diagram by an appreciable amount, while it would reduce the maximum stress on the whole engine to an important extent.

The choice of a type of blowing engine. — From what has been said it will be seen that we have the choice of three separate and very dis-

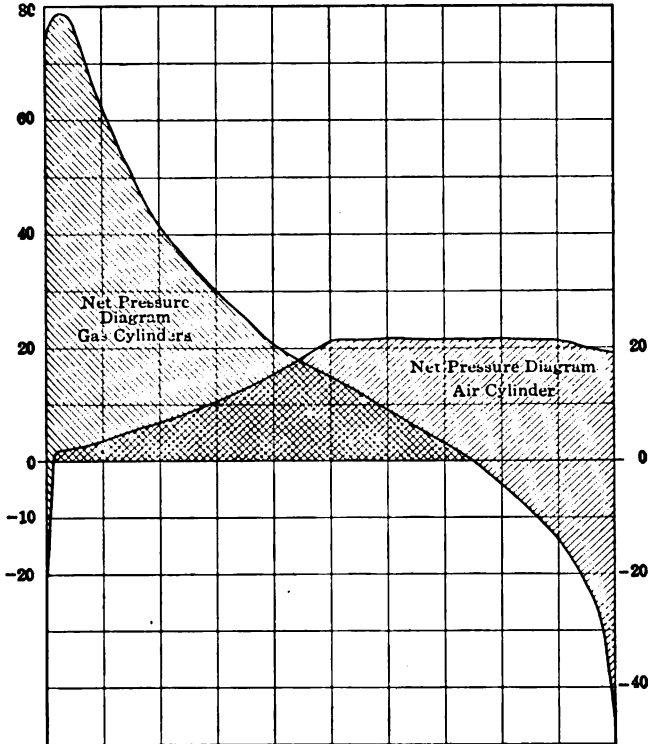


Fig. 123. Net pressure diagram.

tinct types of blowing engines. It would be desirable to make a definite pronouncement as to the superiority of one of these types, but it is not possible to do this for two reasons. First, the whole matter is in a state of active controversy at the present time, with the advantage shifting from side to side as one receives additional light upon one or another phase of the situation. Second, there is no definite solution for all cases because the conditions vary greatly.

At a steel plant which has within itself a vast market for power, the power producing capacity of the blast-furnace gas must obviously be utilized to the fullest possible extent, so that the purchase of other fuel may be minimized or eliminated, and for this object an investment may be made of from four to eight times the annual net saving, depending upon the conditions and the judgment of the owner.

On the other hand a furnace set down in an isolated location with no other manufacturing or mining operation nearby to supply a market for its power is justified in putting in machinery only so good as will secure for it virtual immunity from the purchase of coal for power purposes, and will give the lowest operating cost exclusive of fuel.

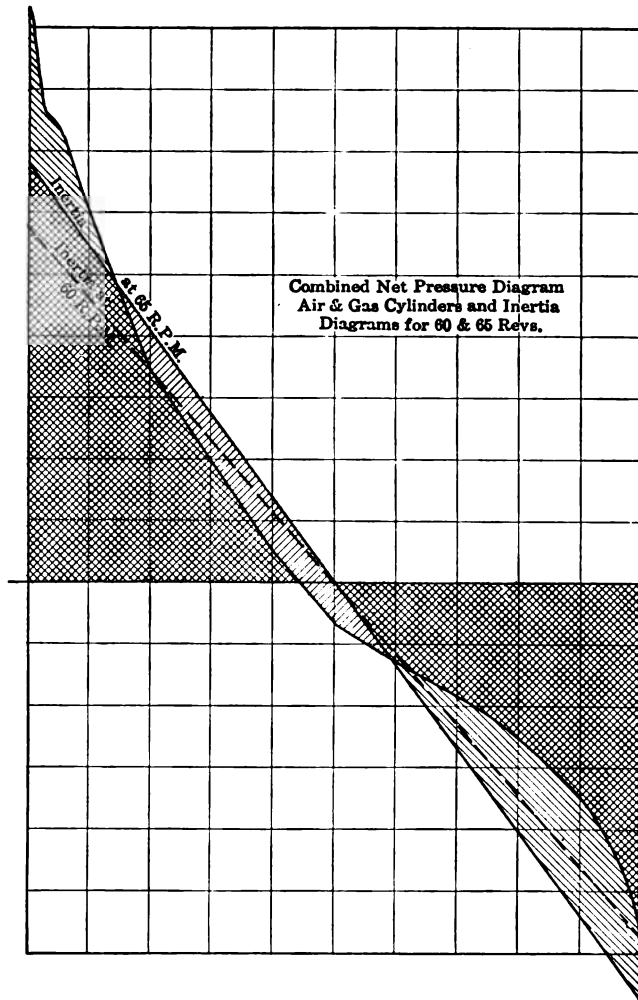


Fig. 124. Combined net pressure diagram of air and gas cylinders.

Under these conditions it is obvious that no decision of this question for all cases is possible even if the actual physical data of operation available were complete, and were unanimously admitted by all parties in the controversy, which is by no means the case. The problem must be solved for each case on its own merits, and the lines of this solution may in a general way be laid down. It may be said in

advance that recent investigation of this subject with details of actual capital and operating costs of gas engine plants by Messrs. H. J. Freyn, formerly of the Allis-Chalmers Company; C. J. Bacon, of the Illinois Steel Company, and Arthur West of the Bethlehem Steel Company, with data on the steam turbine and turbo blower, submitted by Mr. Richard H. Rice of the General Electric Company, have indicated that the fuel cost of power production is by no means the only cost, and in many cases is not even the largest item, but that as we pass from the plain and simple types of machinery of old, to the more refined and economical but expensive types of to-day, the fixed charges due to investment may rise faster than the value of the fuel saved. It is only by considering all these factors that we can arrive at the proper solution in any given case.

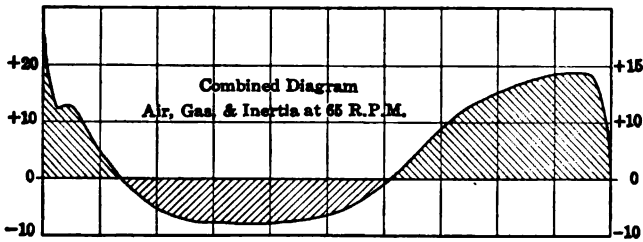


Fig. 125. Combined diagram of air, gas and inertia.

The outline of the solution. — The first question to be asked and answered is as to the value of power for purposes outside the blast furnace. If no market is at hand or can be created this is obviously zero. If on the other hand there is a market it is obvious that surplus power produced by the furnace must meet the competition of power produced by the cheapest means otherwise available. This will generally be determined in a broad way by the cost of coal at the given locality. Granting the existence of the market for the power at a price so determined, and knowing the quantity of gas to be produced by the given furnace plant we deduct from the former 35 per cent. to represent the consumption of the hot blast stoves, and 5 per cent. for other auxiliaries around the plant; the remaining 60 per cent. is the gross amount which must supply the power required for blowing the furnace and that which is to be sold.

Fairly reliable figures are to be had as to the number of thermal units required per horse-power, by each of the different types of prime movers. In the case of the gas engine this can be converted directly into cubic feet of gas required, based on the thermal units per cubic foot of the gas after it is cleaned and cooled and ready for the gas engine cylinders. But in the case of the steam engine and the steam turbine the efficiency of the boiler enters as a factor of much impor-

tance. It has been claimed that this may be put as high as 80 per cent., but the best and the most recent data concerning boilers and their operation with blast furnace gas, indicate that they often reach in practice something less than 60 per cent. This also, however, is capable of investigation and determination for the detailed case in contemplation, and a figure must be taken corresponding to the results which may reasonably be expected. Due allowance must be made for the steam pressure to be used, and particularly for the degree of super-heat desired in the steam, and for the fact that the actual quantity of heat required in proportion to the theoretical, is greater as the degree of super-heat rises.

With this information we may figure the number of cubic feet of gas required to produce a horse-power in the case of the steam engine and the steam turbine, and in this case the thermal value of the gas per cubic foot in a partly cleaned and warm condition may be taken instead of that for its cold condition, which makes a difference of between 5 and 10 per cent. in favor of the steam apparatus. This helps to offset the initial advantage of the gas engine, that it only requires about two-thirds as many thermal units per brake-horse-power as do the steam driven motors.

We can now figure the quantity of gas needed to blow the furnace in each case and subtracting this from the total net heat available we obtain the amount available for the development of power to sell. From this we may determine the amount of such power we can produce in each case and its value, from which the operating cost of its production, exclusive of fuel, must be deducted. Against this we must set up the cost of the investment, the proper rate of amortization, and the proper rate of interest on the capital in each case. By comparing these with the net earnings for the power sold in each of the three cases, we can determine which is the best investment, always remembering that the amount of money available, or which can be raised, is more often than not strictly limited, and that the fact that a fine interest can be earned on an extra two or three millions is of little interest or value if the management cannot raise the extra two or three millions. It is also very necessary to remember that the type of motor determined upon as best to blow the furnace is not necessarily the best for developing power for sale. In fact in my judgment the probabilities are that the reverse is the case. The steam turbine, owing to rotary motion, high steam economy, and ease of supervision has great advantages in driving electric generators, whereas for driving blowers it has no better means to apply to the purpose than the turbo blower whose efficiency is only 70 per cent. as a maximum as compared with 85 per cent. or more as the over-all efficiency of the piston blower. This gives the reciprocating engine, whether steam or gas driven, a

long lead over the turbine for blowing purposes, while the latter has, as outlined above, many advantages over both the former in the generation of electric power.

For all these reasons it seems well to reiterate that each case presents a problem of its own which must be handled without prejudice by someone competent to weigh not only the technical considerations involved, but also that more serious and more difficult question which has wrecked so many engineers and their brilliant schemes: *How much interest will it pay on the capital invested?*

CHAPTER V

HOT-BLAST STOVES

IN the third decade of the nineteenth century James Beaumont Neilson, who from plain beginnings had made for himself a distinguished position as a gas engineer and authority on matters of combustion, was consulted by a furnaceman as to the reason for the very unsatisfactory work of his furnace, particularly in summer.

This started Neilson on a long investigation. Among other things he experimented with the use of preheated air on gas burners and on blacksmiths' fires and found that the effect was a marked increase in the brilliancy and intensity of the combustion. In 1828 he took out a patent on the use of preheated air in the blast-furnace, but even after surrendering two-thirds of his patent to furnace owners he had the greatest difficulty in obtaining a chance to make a trial of the process.

Finally after several years of effort and after overcoming the most factitious and unreasonable objections to changes in insignificant details such as the shape of the blast pipe, he made a demonstration and, while the increase in blast temperature was only 80° F., the results were so obvious that the system was at once adopted and higher temperatures applied.

Then he was at once thrown into another difficulty — that of preventing the overthrow of his patent by a combination of Scotch furnace owners who took a pledge to break his patent virtually "by legal means or otherwise" in order to avoid the payment of his moderate royalty of 1s. per ton, though the saving effected amounted to 32s. per ton.

It is rather a relief to realize that such piracy, which we have been taught to regard as the product of our own times, flourished even in those "good old days."

It is still more pleasant to know that after innumerable trials which went thrice to the House of Lords, Neilson and his associates won, and that on the royalties he finally received he was enabled to pass the closing years of his life in comfort and leisure devoted very largely to what would now be called welfare work.

The results of his invention upon the operation of the furnace were probably very much beyond Neilson's most sanguine expectations, and within a few years the warm blast was used in producing by far

the largest proportion of all the iron made. The reason for this saving so disproportionate to the amount of heat introduced by the warm blast will be explained in a chapter on the thermal action of the furnace. We have here only to deal with the apparatus used for heating the air.

The first apparatus used was in all cases a nest of pipes of some sort in a masonry chamber, first fired independently with coal, later with waste gas from the furnace itself. The gas burned around the pipes while the blast on its way to the furnace passed through them. In early days these stoves were set on the top of the furnace, or if not immediately on top of it at the level of the top and just to one side, as has briefly been described in connection with boilers, so that the burning gas from the open furnace top could be drawn into them. This had the disadvantage that the cold blast had to be taken to the top of the furnace and the hot blast brought back to the bottom with the loss of heat consequent upon that journey, and as soon as the closed top was introduced the stoves were set at the ground level, with great advantages in first cost and in convenience.

The temperature to which the blast could be heated in these stoves was strictly limited by the fact that the pipes constituting the heating surface were rapidly destroyed if a certain temperature, found by experience to be about 900° F., was exceeded by even a small margin, and if the stoves were fired while no blast was passing through them to cool them off, they might be completely destroyed in a period of an hour or two.

To meet this condition the late Sir William Whitwell conceived the idea of applying to this service the regenerator previously invented by Sir William Siemens, which consisted of a pair of chambers filled with brick work, through which ran a great number of passageways arranged to present as much surface as possible.

Through these passage ways of one chamber the hot waste gases of combustion were passed for an interval sufficient to heat the bricks to a high temperature; then the gas was cut off from this and thrown into the second chamber, and the air to support combustion was drawn through the first chamber, from which it absorbed heat by direct contact with the hot surfaces of the bricks. When a sufficient amount of air had passed to lower the temperature of the bricks below that which would impart the required temperature to the air, the gas currents were again reversed in relation to the chambers, the gas being put back through the first one and the air currents being drawn through the second.

For melting crucible steel, the first purpose to which Sir William Siemens applied his invention, the hot air for combustion was drawn through the checker work under the action of the stack draft, the

pressure within the checkers, therefore, differed by only a few inches of water from that of the atmosphere, and masonry construction throughout was sufficient for tightness under this difference of pressure.

In order to apply this system to the blast-furnace, however, the chambers had to be so constructed as to withstand the pressure of the air after compression to the pressure required for the blast-furnace, because obviously the blowing engines could not handle blast heated to a temperature of 1000° F. or so. Therefore, the blast must be compressed first, and after heating must go directly to the furnace.

For this reason Sir William Whitwell built his stoves in the form of cylindrical chambers with a top either cylindrical or dome-shaped to prevent deformation under pressure. The bottom was flat because prevented from deforming by the weight of brickwork upon it. The shell of these chambers was of iron (now steel) plate, riveted together air-tight and strong enough to resist the maximum blast-pressure expected.

There was also another change in the conditions as compared with those of the steel-melting furnace. There the gas to do the heating had already been burned and was simply hot waste gas. The waste gases of the blast-furnace, on the other hand, are not particularly hot, but are highly combustible, and so must be burnt for use in the regenerator and in order to provide a gas burner and combustion chamber these firebrick stoves required, therefore, four connections. First an opening for the gas burner, second an opening to the draft stack, third a connection for the cold blast from the blowing engine, fourth a connection for the hot blast to pass to the tuyères of the furnace.

All of these openings were required to be alternately closed air-tight and opened at frequent intervals, and must retain their tightness under conditions of temperature injurious to any metal available for construction. This meant that all metal parts around these openings had very largely to be water-cooled. The brick stove, therefore, brought many annoyances and difficulties of operation in its train, and, while it gives blast temperatures about 50 per cent. higher than those permitted with the iron-pipe stove, its first cost is greater, and this with the inconveniences and difficulties of operation and maintenance resulting from the conditions described above, retarded its development somewhat, so that a few plants have continued to use the iron-pipe stove, but except in charcoal practice they are rapidly disappearing.

With this general view of the situation we may proceed to describe the two classes of stoves.

The iron-pipe stove. — This stove had a development which lasted about a half century before it was stopped by the preponderating advantages of the brick stove, and in this interval a type of construction was evolved which was almost universally used. This consisted of a

large red-brick chamber lined with firebrick, beneath the brick floor of which passed horizontal pipes with nozzles or connections on their top surface, and a vertical partition in their central plane. On these were arranged U-shaped pipes reaching practically to the top of the chamber, through which the air had to pass on its way from the blowing engine to the furnace; short-circuiting of the U-pipes was prevented by the central vertical partition. Around these pipes burned the furnace gas entering at one end and passing through the rows of pipes and through the baffle walls to the other end, where at last it passed out of the stack.

An excellent design of this type of stove is shown by Figs. 126, 127, 128 and 129, which illustrate a stove built by the Longdale Iron Company at its plant at Longdale, Virginia, under the designs of Mr. H. Firmstone, the president of the company. Fig. 126 is a vertical longitudinal section, Fig. 127 a vertical transverse section, Fig. 128 a sectional plan, Fig. 129 a detail of the U-pipes.

It will be seen that upon a masonry foundation rests a series of cast-iron bedplates strongly bolted together and planed on their top surfaces. Upon these rest the bed pipes, square in cross section, with a central vertical partition and with three lateral nozzles on each side, in addition to the nozzles for the pipes on top.

None of these bed pipes have any connections on their ends except that the outer chamber of the bed pipe at one end is prolonged into an inlet nozzle, and the outer chamber of the pipe at the opposite end is similarly prolonged into an outlet nozzle. Of course, these end chambers are without the lateral nozzles which connect the chambers to one another. The U-pipes are all of elliptical section in order to get a maximum of heating surface for a given area, and the nozzles on the bed pipes are similarly elliptical in section and of the same size as the end of the U-pipes, these ends being enlarged by a sort of collar cast on them which projects outside the body of the pipe about a half an inch, and which fills the spandrel between the two ellipses to a straight line, this is the shape of the exterior of the nozzles on the bedplates also.

It is perfectly obvious, on account of the central vertical partition in the bed pipes, that there is no passageway for the air except through the U-pipes, and the bed pipes being joined in series, with the U-pipes in parallel, the air passes through an entire set of U-pipes on one bed pipe as a single unit, thence to the next bed pipe, and through all the U-pipes on that simultaneously, and so on.

The joints. — The principle of these stoves is obviously very simple, but their construction and the maintenance have developed a number of problems. The joints between the U-pipes and the bed pipes are universally sealed with what is known as a rust joint, a mixture of

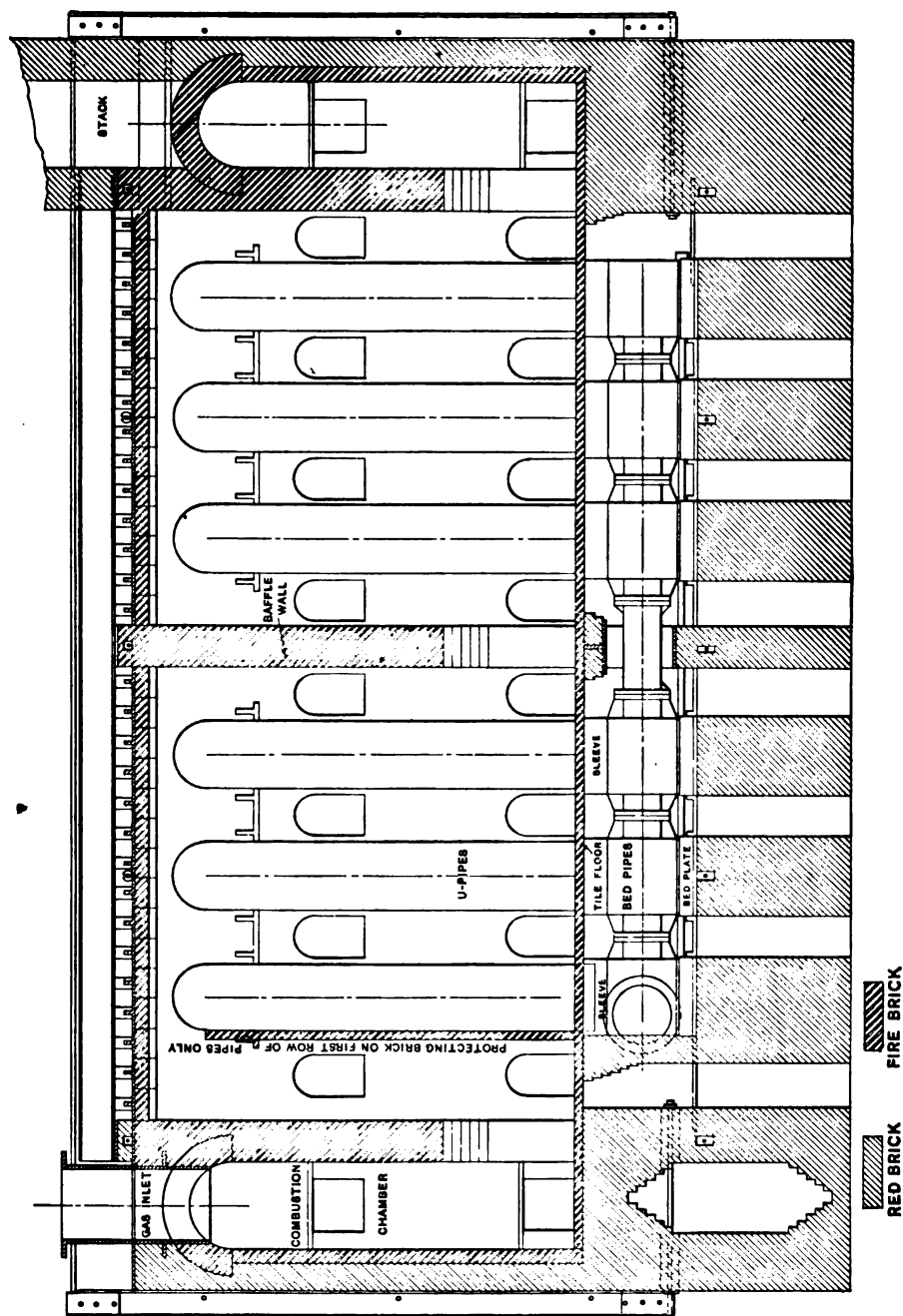


Fig. 126. Iron pipe stove, Glendon type; longitudinal section through center.

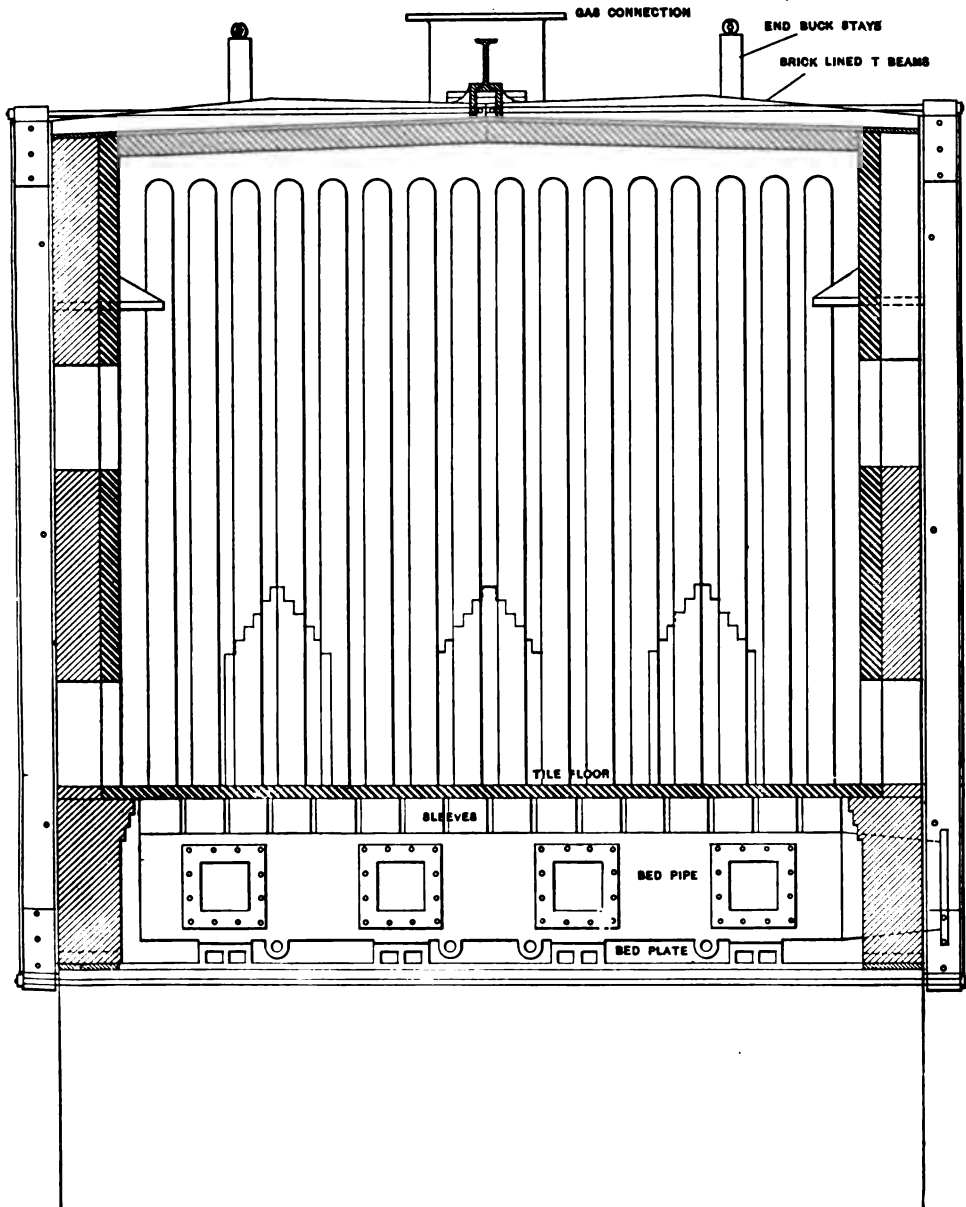


Fig. 127. Iron pipe stove, Glendon type; transverse section.

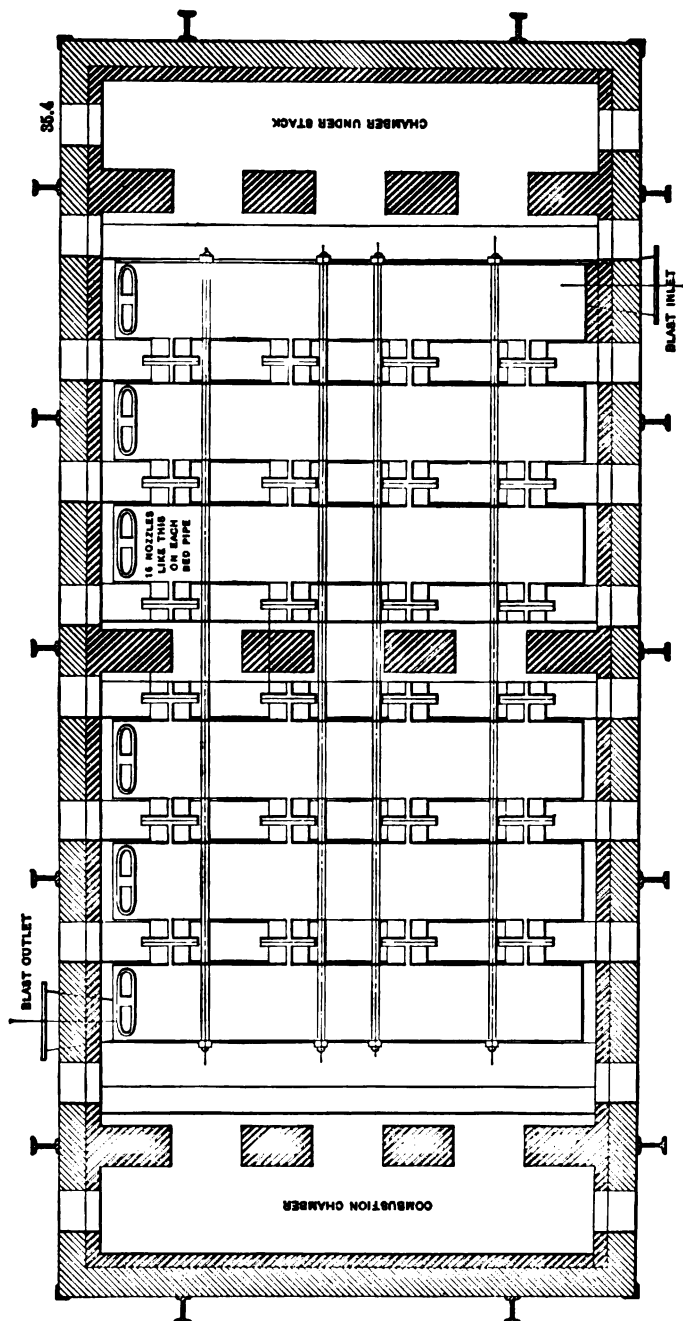


Fig. 128. Iron pipe stove, Glendon type; sectional plan.

fine iron borings and sal ammoniac made into a stiff paste and caulked into place. This mixture rusts with great rapidity; this converts the whole into an homogeneous mass of iron oxide, which is firmly cemented to the adjacent surfaces of solid metal.

A cast-iron sleeve is slipped over each of these joints and the iron borings run down between it and the surfaces to be sealed. The sleeve is large enough to go over the nozzles on the bed pipes

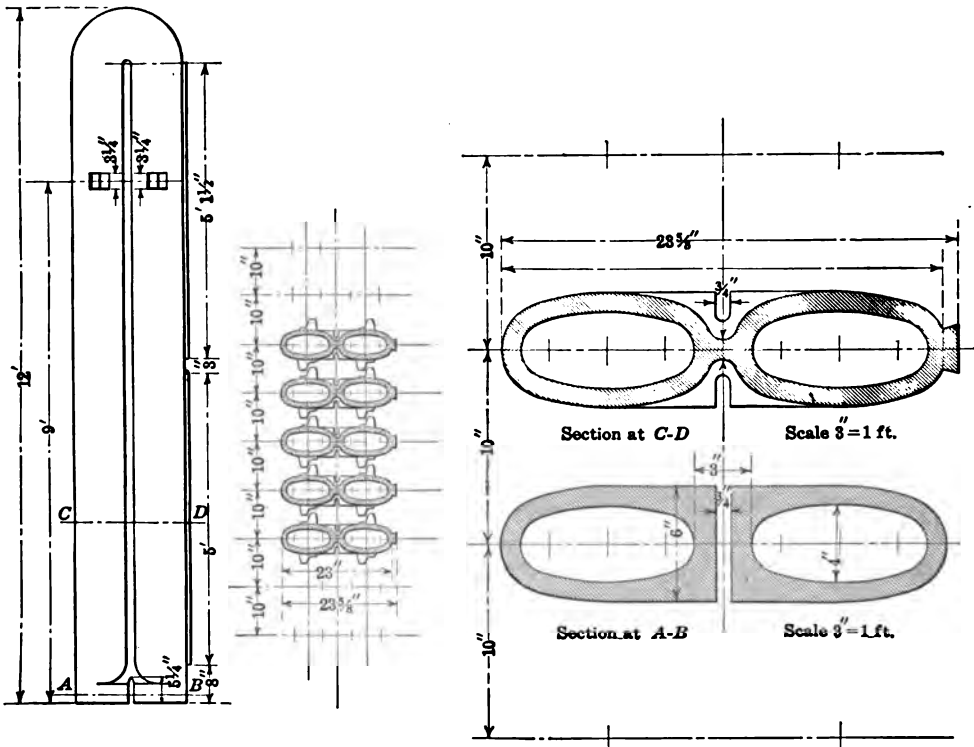


Fig. 129. Heating pipes.

and the ends of the U-pipes, and about 10 in. in depth, so as to extend 5 in. on each side of the joint when resting on the bed pipe. When this is properly done a first-class joint is secured. The joint is preserved as far as possible from the direct heat of the flame by a floor of flat tile bricks laid between the rows of pipes and resting on the sleeves so as to make a fireproof brick floor above the level of the joints.

The U-pipes immediately exposed to the gas coming in from the combustion chamber receive the severest treatment, and these are protected from the direct action of the flame by casting a dove-tail on the side of the pipes placed next to the combustion chamber and

sliding over this dove-tail firebrick tiles with a similar dove-tailed slot. These are put on the pipes so as to cover them from top to bottom on the side next to the combustion chamber and greatly increase their life.

Baffle Walls. — In order to prevent the gas from the burners from passing along the top of the stove to the stack without going down around the pipes, baffle walls are built as shown, with openings through their bases through which all the gas has to pass. This forces the gas current to the bottom twice in its course to the stove and secures a good distribution of the flame over the surface of the pipes.

The roof of the stove. — Many stoves have been built with arched roofs, but these are a great inconvenience when U-pipes have to be taken out and new ones put in, as unfortunately happens not infrequently with this type of stove; and to tear out a portion of this firebrick arch every time a pipe has to be changed would add considerably to the expense and delay caused by the operation.

The Longdale stoves were, therefore, covered by long cast-iron T-beams whose lower surfaces were of jaw-shaped or dove-tailed section. These were lined with tiles or shaped firebricks, the upper part of which fitted into this jaw-shaped section, while the lower part projected out a little beyond the edges of the T-beam. These "shapes" were slid in from the end of the groove and laid in fireclay to make a tight joint and to hold them in place.

In small stoves one end of this T-beam rests on one wall of the oven and the other on the other, but in a large stove, such as that shown here, the span would be too long for necessary strength, for convenience in handling, and for cheapness in casting the beams, therefore a steel I-beam runs down the center of the oven above the T-beams, and these were cast in two pieces, with the joint in the center, the end at the joint having a hook which rests on the lower flange of the I-beam. This excellent construction gives strength and complete protection to the iron work of the roof from the flame, together with convenience and accessibility. Moreover, this construction makes a level top for the stove, convenient to work upon.

This latter is important because when changing pipes shear poles of relatively short and convenient length are set up on top of the ovens resting upon the T-beams, and by this means can be placed exactly where desired, which could not possibly be done with an arched roof. By the use of this construction, where a U-pipe requires to be replaced the half-length T-beams immediately above it can be removed to make room for the operation and then restored to place after it is completed with a minimum of labor and time and without requiring work by masons.

The shape of the pipes. — The elliptical shape of the pipes is due

to a desire to obtain maximum surface for a given area, which may seem at first sight unnecessary, because it might be thought that the area was unobjectionable and that it would be simpler to make the pipes round and not bother about the increased area.

This, however, is open to two objections. First, the length of the bed pipe required for a given number of U-pipes would be greatly increased, which would be objectionable from every point of view, and second, velocity is a matter of much importance in securing proper transfer of heat, much greater transfer being effected at high velocities than at low. Therefore, by constricting the area the velocity of the air passing through the pipes is increased and the temperature obtainable with a given amount of heating surface thereby increased also.

Many stoves have been built with round pipes, and at the end next to the combustion chamber this is probably wise, because the relatively narrow cross section of the elliptical pipes makes them bend about much worse under the influence of the flame than do circular pipes whose diameter is equal to the major diameter of the elliptical pipe. But in the rows which are further from the combustion chamber this does not hold to anything like the same extent, and there is probably ample justification for the use of the elliptical section in those rows.

Two types of iron-pipe stoves.—Stoves of this general type are divided into two classes, known respectively as the "Glendon" and "Durham," from the former well-known works in the Lehigh Valley, which respectively used and advocated the two types.

There is no essential difference in the construction of these two types, the only difference being in the directions in which the flame and air pass through them. The Glendon stove, as illustrated by the drawings, Figs. 126-129, is on the counter-current principle. The cold air enters at the draft stack end of the stove and progresses through increasing temperatures to the combustion chamber end, where it is discharged, while in the Durham stove the opposite procedure is followed. This latter at first sight is amazing and contrary to reason, but it appears to be an established fact that higher blast heats can be obtained from stoves of this kind than can be obtained from the Glendon type. The latter type is definitely limited, if it is to give long life and low repair cost, to 850° F., while from 900° to 1000° may be obtained in the Durham type of stove. This is for the reason that when the counter-current principle is used the pipes next to the combustion chamber carry air already heated up almost to the limit of temperature for the stove, and are exposed on the outside to the flame directly from the combustion chamber. They are, therefore, not cooled off or protected on either side, and if very moderate

temperatures be exceeded they will fail in one way or another under this combined assault from within and from without.

In the Durham stove, on the other hand, the coldest air passes immediately into the hottest pipes and cools them down to such a degree that they can withstand the external heat. Of course, in this type of stove the waste gases must pass off at a temperature at least 200° or 300° higher than that of the hot blast they are discharging, otherwise the last rows of pipes would be worthless and would absorb no heat, while in the Glendon type of stove the hot gas may be discharged at a temperature several hundred degrees lower than this and still impart heat to the cold blast just entering.

I do not know of a single case in which any investigation has ever been made of the thermal efficiency of iron-pipe stoves, but I am convinced that that of the Glendon type is considerably higher than that of the Durham. On the other hand, if there be no use for the gas saved by this superior stove economy, as was generally the case at plants where these stoves were in service, then it is much better to burn this gas even though the economy of the operation be low, and convert its heat into increased blast temperature which exercises a beneficial effect upon the fuel economy of the plant as a whole.

Firebrick stoves.—The early stoves of this type were of large diameter in comparison with their height, and contained four passes, each passage of the gas vertically through the stove being called a pass. Following the original Whitwell patent a vast number of modifications sprang up and the shape of the stove has undergone an alteration which has now given it a height of four or five times its diameter.

The number of passes has been the subject of experiment, as has almost everything else connected with the stove. It was gradually realized that the fourth pass frequently contributed very little to the heat of the blast, and as every additional pass meant giving up valuable space in the stove for partition walls, with added complexities of brickwork at the top and bottom to form safe and durable passages from one pass to another, the number of passes was reduced to three, to two, and finally to one.

Stoves of this latter type were brought out by Mr. Hugh Kennedy some thirty years ago, it has a single pass straight through from the bottom to short chimneys on the top.

This did away with the necessity of building a chimney for the stoves, and simplified the brickwork to the last degree, but the results in practice were unsatisfactory as the stoves did not give the heat desired. They have, therefore, practically passed out of use, and as a result of this and of the gradual disappearance of the four-pass type almost all the stoves built in recent years have been either of the two-pass or the three-pass variety.

The three-pass central combustion chamber stove. — The reason for three-pass stoves is that an odd number of passes brings the gas to be discharged at the top of the stove and by adding a relatively short stack immediately on its top we can obtain the draft necessary without the inconvenience of returning the gas back to the ground level and providing a separate stack for it.

The combustion chamber is central for the reason that, as the average temperature of the brickwork is higher around the combustion chamber than elsewhere, it is likely to expand to a greater extent there than anywhere else. When the combustion chamber is in the center this excess expansion takes place along the central axis of the stove with complete symmetry in all directions, while the fact that the annular wall which constitutes the outside of the combustion chamber and presumably attains the highest temperature, does not support anything at the top, makes it perfectly free to expand and contract without the destruction of any part of the stove. It is claimed on behalf of the central combustion chamber stove that the side combustion chamber locates this unequal expansion unsymmetrically in the stove with a tendency to greater stresses on one side than on the other.

Moreover, the last pass is very much lower in average temperature than the combustion chamber, and in the McClure stove this relatively cool pass extends all around the outside of the stove and tends to cut down the radiation losses below what they are when the combustion chamber is just within the stove wall on one side.

The McClure stove. — These two ideas underlie the design of the McClure stove, which is one of the best-known types of 3-pass stoves, built by the George W. McClure & Sons Co. This is shown in sectional elevation by Fig. 130, the horizontal section at the level of hot-blast outlet is shown in Fig. 131, a horizontal section of the checker work is shown in Fig. 132. It will be seen from Figs. 130 and 131 that gas and combustion air are introduced at the bottom, pass up through the central combustion chamber, down through the first four rings of checker work to the bottom of the stove, where they pass through arches in its intermediate wall, and so up through the exterior row of checkers to the top, where they pass out through the chimney valve and up the stack. The stove is drawn as "on blast," so the chimney valve is shown shut and the arrows are shown in the reverse direction to that described and illustrate the course of the blast as it passes through the stove and finally out the hot-blast opening.

It will be seen that the stove contains two domes, one a spherical one resting on the intermediate wall which separates the second and third passes of the gas and one a conical one which lines the conical steel dome of the stove shell and prevents its destruction by heat. Fig. 133 shows a perspective view in section of the lower portion of this stove.

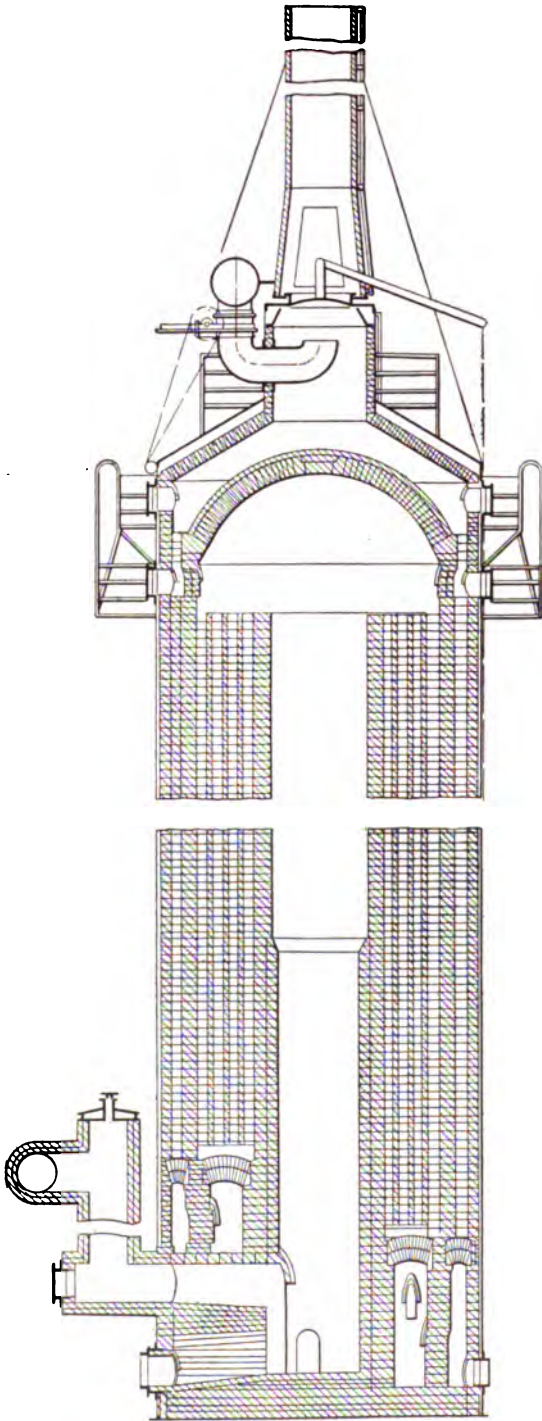


Fig. 130

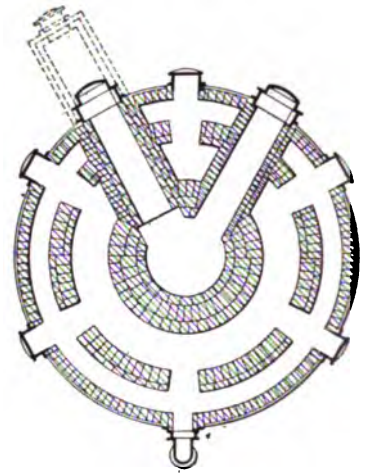


Fig. 131

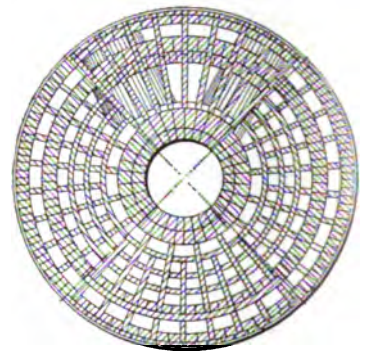


Fig. 132

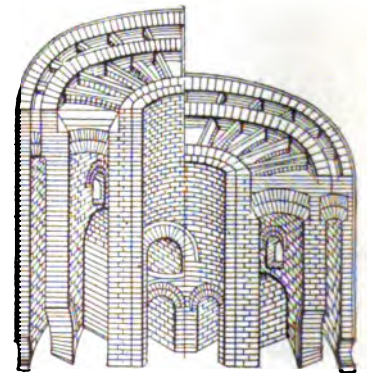
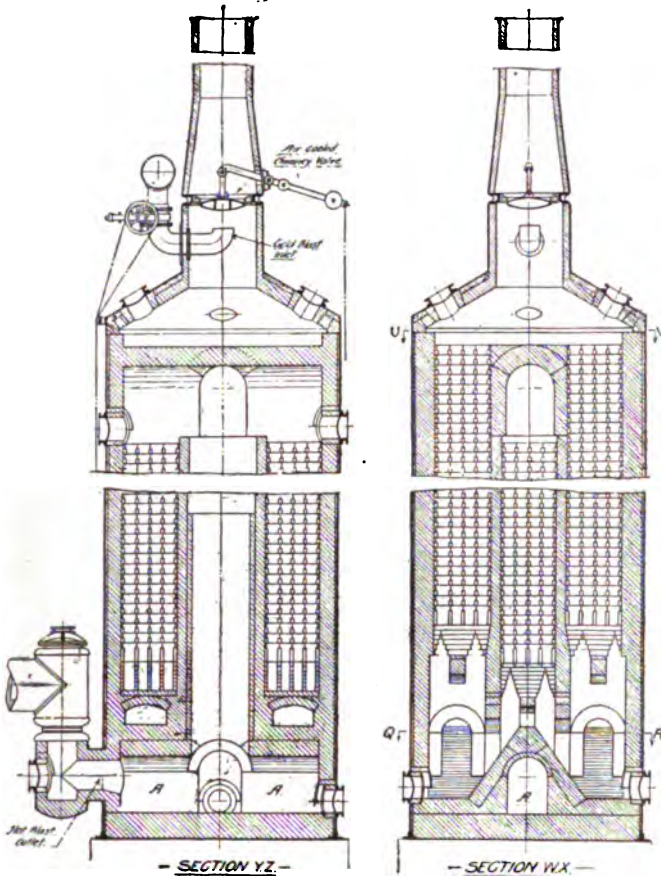


Fig. 133

Figs. 130, 131, 132, 133. M'Clure three-pass stove.

The cold-blast valve is a flat bell valve rising against a seat bolted into the top of the stove and renewable through the door in the stack in case of necessity. The cold-blast elbow directs the air up against the under side of this valve in order to keep it cool and by this means dispenses with water-cooling for it.



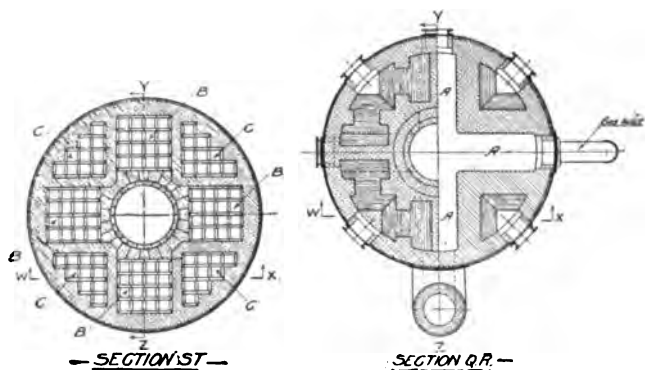
Figs. 134, 135. Roberts three-pass stove.

Cleaning doors for the space outside the spherical dome are provided just below the top of the cylindrical portion of the stove, while cleaning doors for the portion inside the stove dome are a short distance below these and give access to doorways through the intermediate wall which are bricked up when the stove is in operation but which may be opened to allow passage into the stove for cleaning.

Clean-out doors are also provided at the base of the stove, opposite the arches which furnish communication between the second and third gas passes.

The Roberts three-pass stove. — The stove, the design of Messrs.

Frank C. Roberts & Co. of Philadelphia, and shown by Figs. 134, 135, 136, 137, and 138, also uses the central combustion chamber principle, but instead of having the second and third passes annular, the



Figs. 136, 137. Roberts three-pass stove.

space outside the combustion chamber is divided into eight sections by two pairs of parallel walls at right angles to one another whose distance apart is about the same as the diameter of the combustion chamber. This makes four square spaces at the opposite ends of the two principal axes of the stove, and four triangular spaces between these, as shown by Fig. 137.

The intermediate dome of the stove, instead of being a segment of a sphere, is cross-shaped in plan, the tops of the two crosses being arched over with intersecting arches. The gases of combustion pass up through the central combustion chamber, then down through the four square areas within and under this cross-shaped intermediate dome, to the bottom, then up again through the triangular areas, and so to the stack.

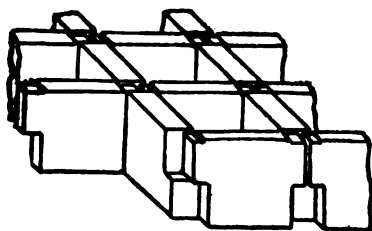


Fig. 138. Checker work for Roberts three-pass stove.

The stove, instead of being built of circle bricks and straight bricks laid on the flat, as is the case with the McClure stove, is built up of tiles set on edge and interlocking with one another, as shown by the isometric view, Fig. 138. The checkers are square, instead of having radial ends and circular sides, as in the McClure stove.

This design is used so as to control the gas current to some extent and prevent its traveling too much on one side or another, as it has sometimes been claimed to do in the case of the annular passages of the McClure stove. The cold-blast valve and inlet pipe are necessarily

located at the top and the current of air is directed against the chimney valve to keep it cooled as in the McClure stove.

Two-pass stoves.— Commonly two-pass stoves have shared the preëminence with three-pass stoves in the best modern practice. In the case of the two-pass stove the valves are all at the ground level, so that any blast leakage has at least a fair chance of being detected by the sound it makes, and the interior construction of the stoves is the simplest possible.

Only a single brick dome is required, and therefore the gas in passing from the combustion chamber to the checkers has only to pass over the top of the combustion chamber wall and down. At the bottom the arrangement of flues for gathering burnt gases from the checker work and leading them to the chimney valve, and distributing the blast from the cold-blast valve to the checkers is also extremely simple. Moreover, no space is given up to any intermediate wall of any kind.

Two-pass side combustion chamber stoves.— Some operators claim that, while the central combustion chamber is theoretically correct, in practice the side combustion chamber type gives little or no trouble if properly constructed, and, owing to the fact that the side combustion chamber is immediately adjacent to the gas and clean-out openings, it is easier to keep clean than is the central combustion chamber because of the distance of the latter from the operator, and the consequent necessity of removing the accumulation of dirt and slag in the center of the stove at a distance of 8 to 12 ft. from the closest point which the operator can reach. Moreover, the tendency of the blast to wander in the checker work of the two-pass central combustion type of stove seems to be established beyond question, which is a serious drawback to its efficiency.

The cross section of the checkers for a stove of this type of a given size is almost twice as great as that of the checkers of the second and third passes in the McClure stove, and this excess area causes a very low velocity through the checkers, so that a very small difference in draft on one side or another will cause a difference in the flow on that side.

The chimney is necessarily at one side in this type of stove and the gas passing through the checkers nearest it has the shortest path to the stack, and for that reason the greatest flow will generally take place on that side, with corresponding inactivity in some other region, whose usefulness is thereby greatly reduced. This is for a reason which must never be forgotten in matters of heat conductivity to or from a fluid, particularly a gas, that high velocity of the fluid absorbing or emitting the heat is of the same order of importance as temperature-difference and surface.

Efforts have been made to overcome this tendency by equipping each stove with two or even three chimney valves, but while this is undoubtedly good practice, and while two such valves are becoming recognized as correct practice, even for the side combustion stove, it does not, in the experience of some skilled operators, overcome the

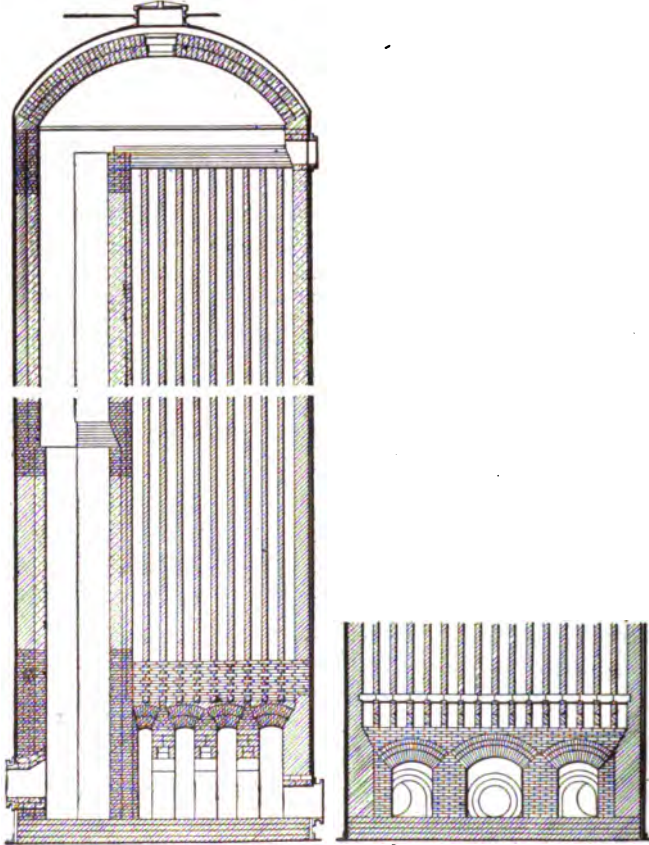


Fig. 139. Section through combustion chamber.

Fig. 140. Section through arches at base of stove.

Figs. 139, 140. M'Kee Nelson stove.

difficulty completely. Some recent work done in Germany makes it appear possible that we have neglected this question of velocity in the passes far more than its importance warrants and that our stove practice may be materially improved by paying more attention to it.

For these reasons some operators and engineers prefer the two-pass side combustion chamber stove.

The Nelson two-pass stove. — This stove is built by Arthur G. McKee & Co., contracting engineers, Cleveland, Ohio. The principal

claims for the stove are that it secures a very large area of heating surface in proportion to the total cross section of the stove, and that there is in it a very small percentage of any brick except standard shapes, regularly kept in stock by brick manufacturers.

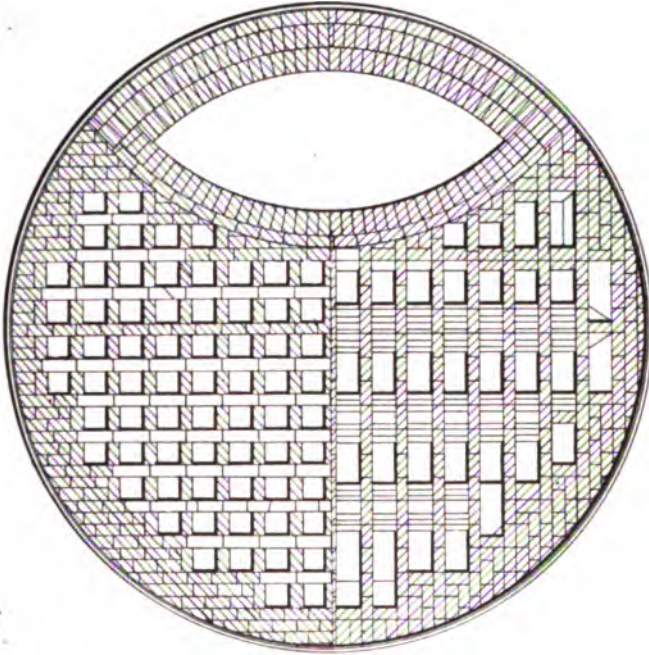


Fig. 141. Horizontal sections of M'Kee Nelson stove.

This stove is clearly shown by Figs. 139, 140, and 141. It will be noticed that the back or inside wall of the combustion chamber is given a radius or a curvature the same as that of the front wall. This is a matter of much importance because when this wall has too flat a curvature it becomes a very weak arch and does not resist the thrust due to the expansion of the checker work, and in the past, before experience had taught this costly lesson, many stoves were put out of commission and required to be relined long before they would have been had this point been properly guarded.

The checkers are square in shape and well bonded, and the walls between the flues on which the checkers are built are substantial, so that while these stoves have only been in use for some four or five years, they are well regarded and have given good service.

Roberts two-pass side combustion chamber stove. — In order to meet the views of those who desired a stove of this type Frank C. Roberts & Co. also furnish one of the design shown by Figs. 142 and 143.

This stove uses exactly the same checkers as the Roberts three-pass stove. It is so completely shown by the drawings that no fuller description is necessary.

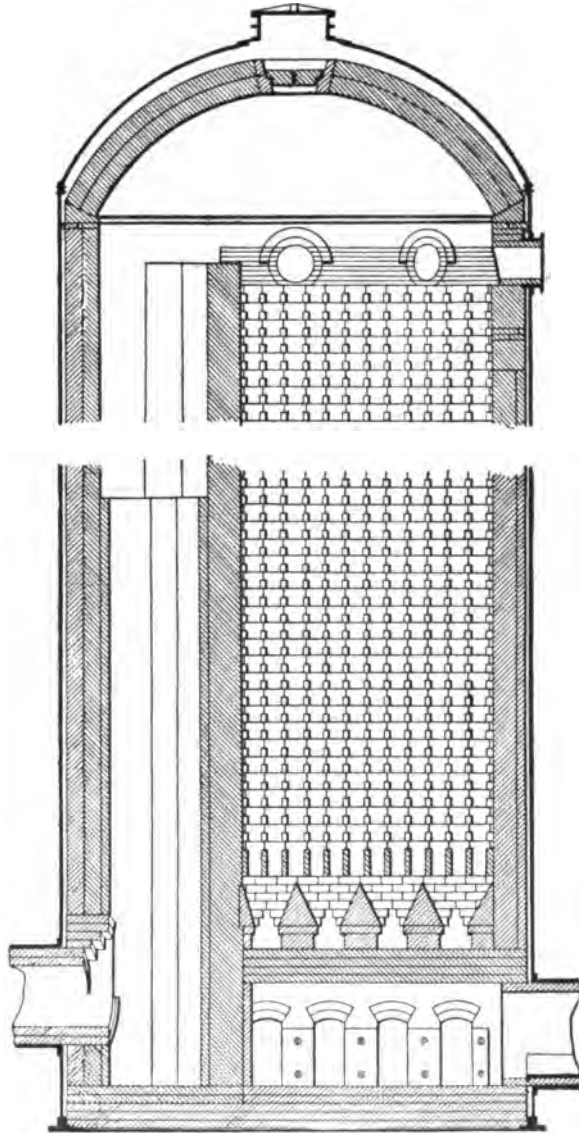


Fig. 142. Roberts two-pass side-combustion stove — vertical section.

The two-pass central-combustion chamber stove. — Some operators, while admitting the disadvantage of the three-pass construction and preferring the two-pass type, consider the central combustion chamber

the best, and a type of stove designed by Frank C. Roberts & Co. to meet this demand is shown by Figs. 144 and 145.

The type of checker work used in these stoves is of the same type as that used in the three-pass stove, except that, instead of being designed for square checkers, it is designed for radial bricks on two sides and circumferential ones on the other sides. This checker work is shown in perspective view by Fig. 145. The construction of the stove is obvious from the drawings and from what has been said of the principles on which it is based. It is provided with the ordinary accessories in the way of cleaning doors, etc.

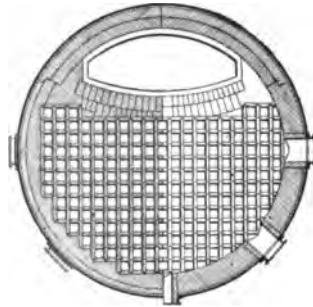


Fig. 143. Roberts two-pass side-combustion stove — horizontal section.

Mr. Julian Kennedy was one of the first designers of two-pass central combustion chamber stoves and used, instead of brick checkers, hollow tiles, with openings through the center about 9 in. square. The sides of these were radial and the fronts and backs circumferential, so that when stacked up in the stove they made a series of radial checkers whose circumferential width gradually increased from the combustion chamber back to the lining of the stove.

The objection to this construction was that a special shape of hollow tile was needed for each ring of checkers and that the partition wall between each two checker openings being made up by the adjacent sides of two of these hollow tiles was split vertically, therefore its strength was not great, and if one of these gave way it was likely to turn over and obstruct the checker completely. If this happened anywhere in the checker except right at the top it was practically impossible to fix it, and that checker was lost to the stove for the balance of the life of its lining, so stoves now generally have checkers of brickwork built up in the ordinary way.

Stove valves and fittings. — *Hot-blast valves.* — One of the most important details connected with stoves is their hot-blast valves. Long experience with these has now developed a type which is in almost universal use on all stoves, subject, of course, to individual variation in the details. This consists of a mushroom or a poppet valve resting on a water-cooled seat, the valve being supported by a water-cooled stem. The design used by the McClure Co. is shown by Figs. 148 and 149. Commonly the valve is water-cooled as well as the stem, but in the McClure type of hot-blast valve this is not done, the valves are made solid without water-cooling. The reason for this practice is that if water-cooled valves leak they may discharge a great quantity of water into the hot blast by which it is at once absorbed

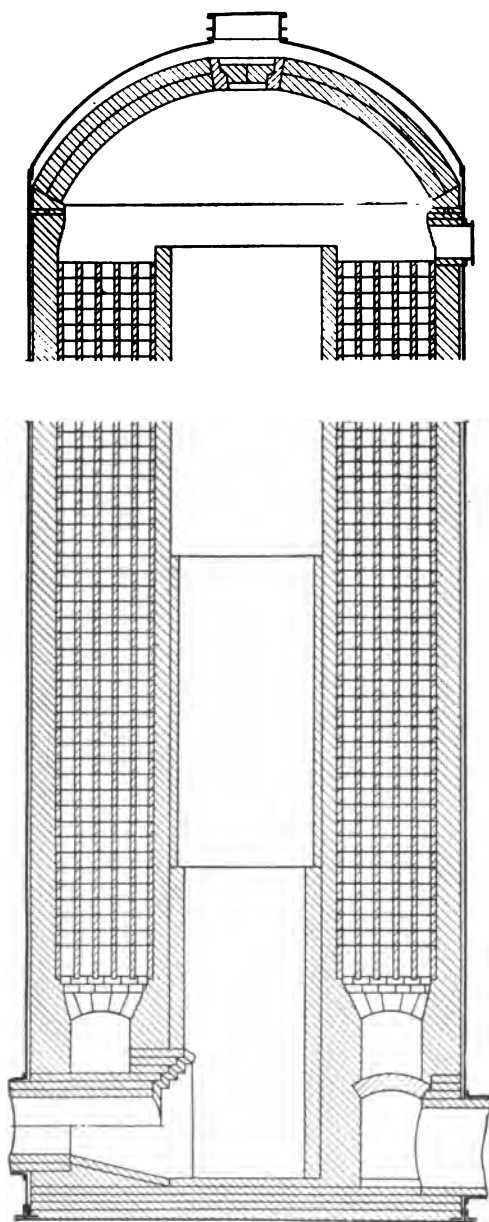


Fig. 144. Roberts two-pass center-combustion stove — vertical section.

without showing the least sign, but the effect of this moisture is highly detrimental to the furnace. Moreover, it is claimed by some experienced furnacemen that hot-blast valves last about as long without water-cooling as they do with it, and that it is better to dispense

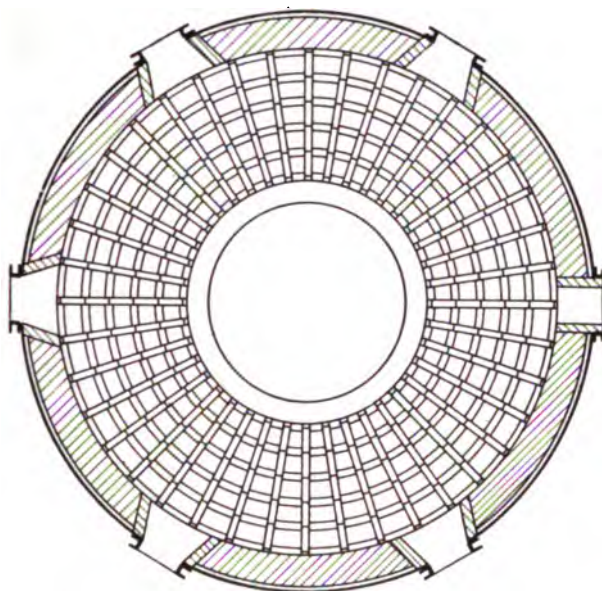


Fig. 145. Roberts two-pass center-combustion stove—horizontal section

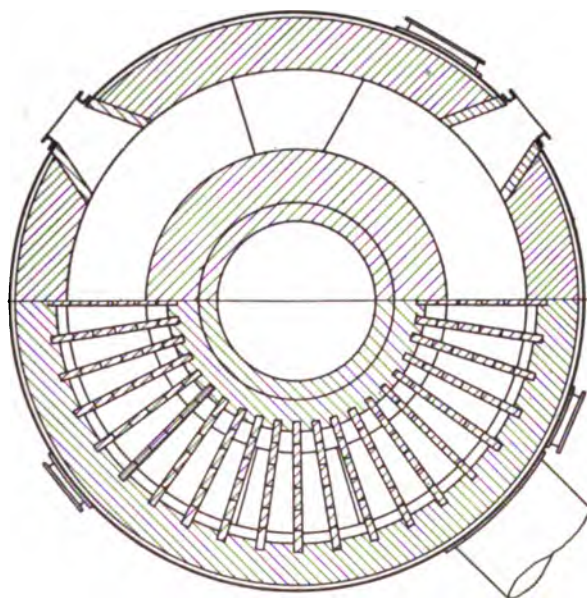


Fig. 146. Roberts two-pass center-combustion stove.

entirely with the danger of leakage even at the price of a somewhat shorter life of the valves.

The stem, of course, must be water-cooled because it must pass through a gland which is required to make a tight joint on it in all

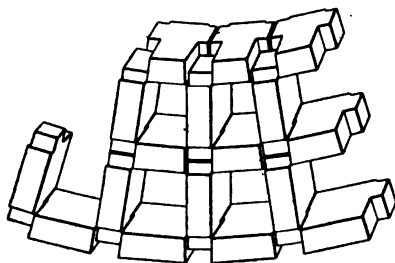


Fig. 147. Isometric view of checkers.

positions. This would be quite impossible with the stem heated to redness as it would be if the valve had been for two hours in the closed position. It was formerly the custom to mount the gland immediately on top of the dome-shaped cap of the hot-blast valve, but more recently the practice has prevailed of putting in a long sleeve, in the present case about 6 ft. long, which

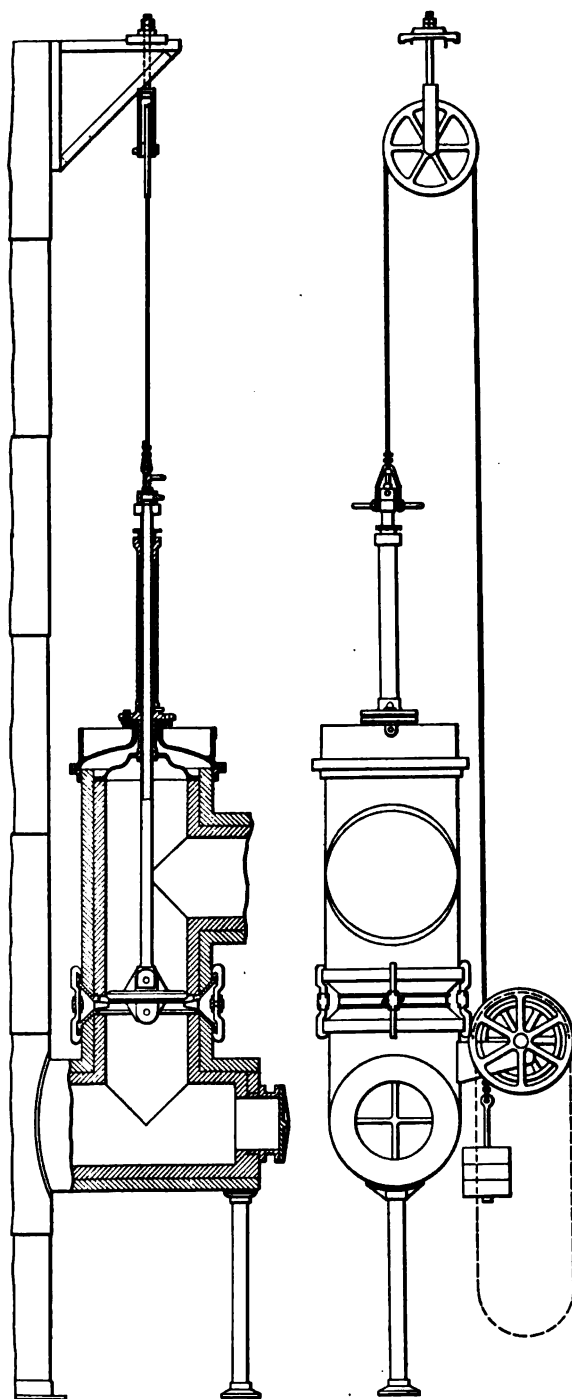
is simply a loose working fit on the valve stem and carries the gland on its top.

The air-cooling on the outside of this sleeve prevents the stem from ever getting very warm and the length of the sleeve is such that the portion of the rod which goes inside the hot-blast valve proper when it is closed does not come anywhere near the gland when raised into its highest position. This has brought about a great improvement in the conditions of operating and maintaining hot-blast valves. It will be seen also that a two-inch air connection is provided at the base of this sleeve whereby additional cooling effect may be secured if desired.

The hot-blast valve body is covered with a cast-steel cap as shown, and this top is provided with a flange which makes a water box of its upper surface, and the water discharged into this, after cooling the stem, keeps it in good shape. This is, however, protected by an inside cast-steel cover resting on the brick lining of the hot-blast pipe. In many cases this cast-steel cover is replaced by two large semicircular firebrick tiles with a hole cut out in their center large enough for the valve stem to pass through, these semicircular tiles resting on the brickwork of the lining exactly as shown for the cast cover.

The water-cooled seat is generally made of bronze, cast hollow to provide for a rapid circulation of water through it. In some cases cast-iron seats with a coil of water pipe cast in them are used, but in good modern practice the bronze seats are becoming almost universal. Very recently steel-plate seats of pressed sections welded together have been tried successfully but are not yet in general use.

It will be seen that the hot-blast valve body is cut entirely in two by this seat and held together by clamp bolts which draw together the top and bottom portions of the valve body so as to make a joint



Figs. 148, 149. M'Clure hot-blast valve.

on the top and bottom of the valve seat. This arrangement is used in order to facilitate the changing of these seats, which owing to the high temperature and the abrasive action of flue-dust to which they are exposed are subject to heavy wear and must be renewed quickly, since the blast must be off, and the whole furnace stopped, in order to make the change. By slacking off the right and left-hand nuts of the clamp bolts and screwing them out until the flat faces on the end of the straight portion of their shanks engage with the flat faces on the seat rings the latter may be forced apart by an amount slightly greater than the vertical height of the shoulder around the valve seat, and the latter can then be slipped out and a new one quickly inserted. When this is properly centered and the hot-blast valve body drawn back to place, the projecting ring or shoulder around the seat of the upper flange holds it securely in place.

The hot-blast valve is suspended from a rope which passes over a high pulley and back to a drum mounted in bearings bracketed to the side of the hot-blast valve casing. The rope is given two or three wraps around the drum and a counterweight equal to the hot-blast valve and stem is attached to the lower end. A hand-wheel on the drum is provided and with this arrangement the stove tender can raise and lower this valve without difficulty. In order to facilitate changing hot-blast valves, when this becomes necessary, the high pulley is now in some cases placed at the top of the stove. This gives ample height to raise the valve, not only to open it but to lift it clear out of the valve chamber. The high suspension also facilitates swinging the valve to one side in order to lower it to the ground. These are details of much importance when valves have to be changed, since they facilitate doing it quickly. For the same reason the bolts used to bolt the outside cap to the hot-blast valve casing should be key bolts, or else the bolt holes should be slotted to the outside so that as soon as the bolt is loosened it may be removed without unscrewing the nut all the way.

The cold-blast valve.— A standard design for this valve has gradually been evolved, and while the individual valves used by different stove builders differ in details, the general principle of all is the same. They are all flat slide valves designed to withstand pressure from one direction only, since this is all that is necessary for this service, and are always operated by a hand-wheel and pinion.

Figs. 150 and 151 show the design of the cold-blast valve used by Frank C. Roberts & Co. Its construction and operation are obvious from the drawings. There is one point, however, which might escape the casual observer and is therefore worthy of mention. The rack on which the pinion works to operate the valve is not rigidly attached to the latter, but is free to slide between the guides shown in

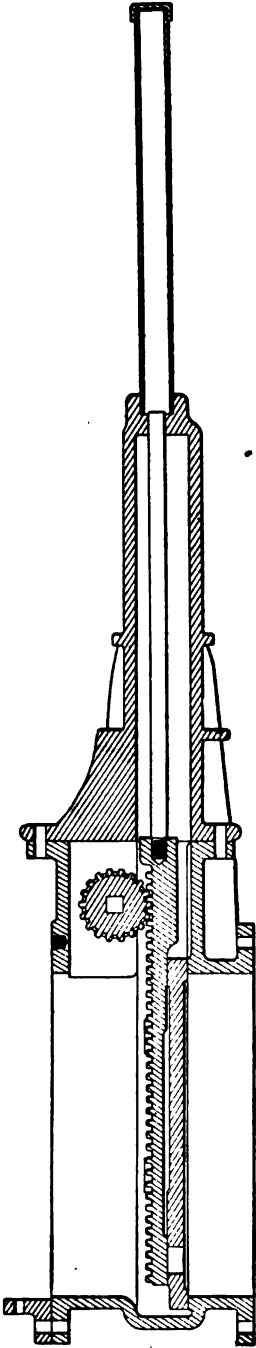


Fig. 150. Roberts cold-blast valve.

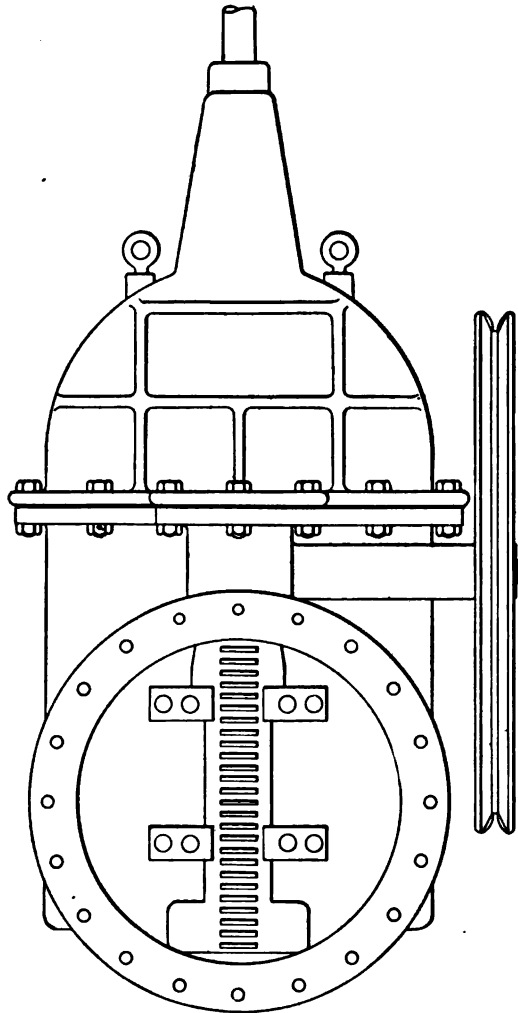


Fig. 151. Roberts cold-blast valve.

Fig. 151 within the limits set by the stops, these come against the guides and through them move the valve proper. The end of the rack is widened out to a T-shape and this covers a slot through the main valve. When the valve is to be opened to put the stove on blast the unbalanced pressure on it is very great, and if the stove tender succeeded in opening it in spite of the friction produced by this pressure, the rush of air into the stove might be so rapid as to do damage.

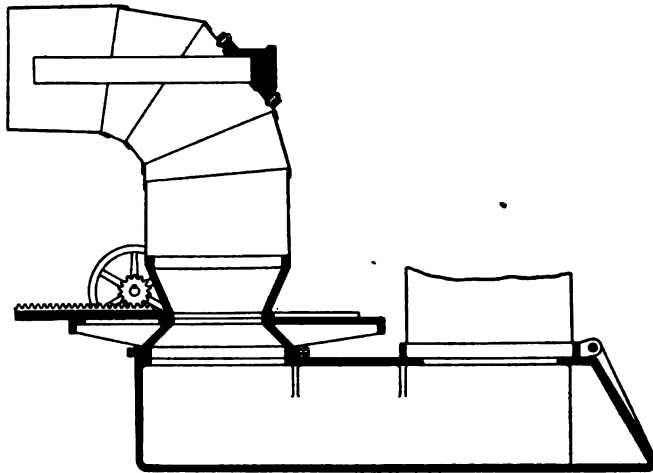


Fig. 152. Spearman Burner.

With the arrangement shown the first movement of the pinion slides the rack proper on the back of the main valve and thus uncovers the port in the latter; through this the air flows until in about a minute the pressure within the stove is the same as that in the blast main; this relieves the friction on the valve, which can then be moved back into the valve housing without further difficulty.

Stove burners. — Only one type of stove burner is in extensive use, known, from its inventor, as the Spearman burner.

An excellent design of this by the Wm. B. Pollock Co. of Youngstown is shown by Fig. 152. The gooseneck rests on a slide supported on a hollow base which serves as a gas inlet. When the gooseneck is in the position shown, the opening in its base corresponds with that in the slide and its end projects inside the burner opening in the stove so that the gas enters and burns with the air which is drawn in around the gooseneck and also through the small pipe in the center. The purpose of the latter is to give more intimate mixture of air and gas, thus giving better combustion.

When the gooseneck is withdrawn its slide closes the opening in the base and the opening in the stove is closed by a cap or door in

exactly the same way as the chimney valve opening is closed in the Stenbakken design. (See Fig. 159 on p. 221.)

Much attention is being paid to stove burners at the present time with a view to securing more perfect combustion by better mixture of the air and gas. Mr. A. J. Boynton, superintendent of the Lorain furnaces of the U. S. Steel Corporation, has put in use an excellent burner which is a decided departure from standard practice. The burner consists of a square casting with a round projecting nose which fits close against the seat ring in the burner opening. This casting is mounted on small wheels so that it can easily be withdrawn to permit closing the burner-opening in the regular way. The gas enters at the rear and passes through a number of flat passages cored through the casting. The spaces between these passageways are about the same size as the passages and open at the sides, these multiple side openings being under the control of a slide on each side so operated as to give the same opening at each air port and to vary the amount from nothing to full opening.

The gas is controlled by an independent bell valve in the supply pipe. This gives complete independent control of both air and gas supply and intimate mixture of air and gas at the nose of the burner.

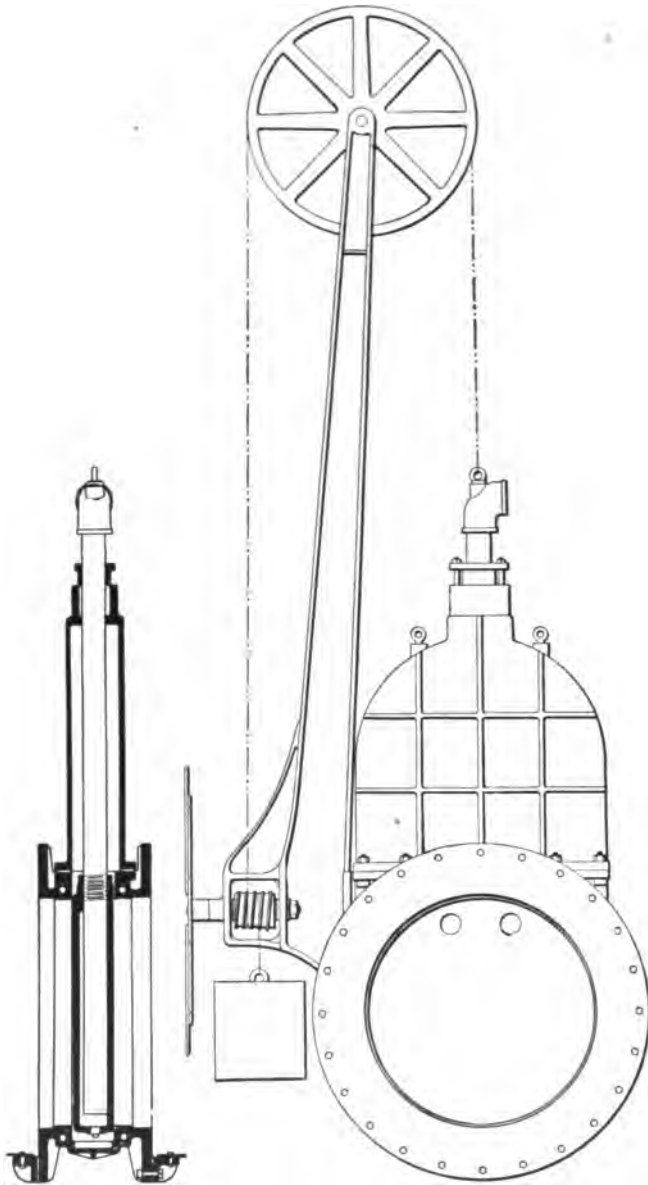
Later developments of burners are described in the chapter on "Combustion of the Gas."

Chimney valves. — One of the earliest forms of chimney valves is of the same form as the cold-blast valve, but very much larger and water-cooled to withstand the action of the hot chimney gases; its seat is also water-cooled. Such a valve designed by Frank C. Roberts & Co. is shown by Figs. 153 and 154. Its construction is so clearly shown by the cuts as not to need much description.

Like the hot-blast valve this valve is counterweighted and operated by a hand-wheel and drum around which the suspension rope passes. The side furthest removed from the stove is turned to a joint on the face and the pressure of the blast when the stove is on blast holds the valve to its seat. When the stove is blown off it then swings comparatively freely and can be raised by the operator without much difficulty.

A mushroom valve of the same type as that used for hot blast has also been largely used in the past. A type of this valve designed by Frank C. Roberts & Co. is shown by Figs. 155 and 156 (page 219). This also is water-cooled and operated exactly like the hot-blast valve.

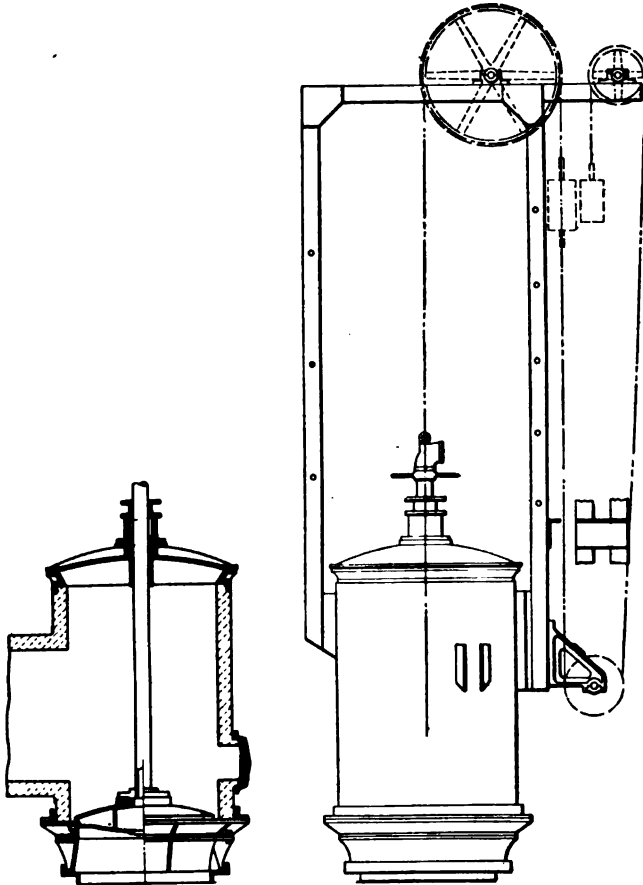
Valves of these two types, however, have proven very large and unwieldy and rather troublesome in operation, and there has been a strong tendency in the last few years to develop a type of valve which was more accessible, could be more easily operated, and which did not require water-cooling. One of the first and most successful of these was



Figs. 153, 154. Roberts slide chimney valve.

the Kennedy-Morrison valve shown by Fig. 157 (page 220). This valve is exactly on the principle of the Spearman burner except that it makes as close a joint as possible against the reinforcing ring around the chimney opening in the stove, so as to prevent the ingress of any outside air to the flue. When the elbow which carries the burnt gas

from the stove to the underground flue is withdrawn its slide seals the flue opening exactly as in the Spearman burner, and the opening in the stove is sealed by a cap held to place by one or more screws mounted in swinging yokes, these screws forcing in the ends of a cross-bar or "spider" pivoted to the center of the cap. (See Fig. 158 on page 221.)



Figs. 155, 156. Roberts mushroom chimney valve.

The Inland Steel Company has in use a modification of this valve designed by its chief engineer, Mr. Ole Stenbakken, in which the gooseneck instead of sliding back and forth rests on a circular seat, the center of the circle being set off from the central plane of the gooseneck proper so that when the gooseneck is revolved around this base it is withdrawn from the stove, the opening is then closed by a cap as in the Kennedy-Morrison burner. The construction is shown by Figs. 158 and 159 (page 221). As these goosenecks are very large and heavy

it is desirable to reduce the amount of movement and effort required to operate them to a minimum and this is admirably accomplished by the rotation of the gooseneck around a vertical axis; its opening, when removed from the stove, is closed by a light steel door.

The chimney valves which are used on the three-pass type of stoves have been shown in conjunction with those stoves and do not need further comment here.

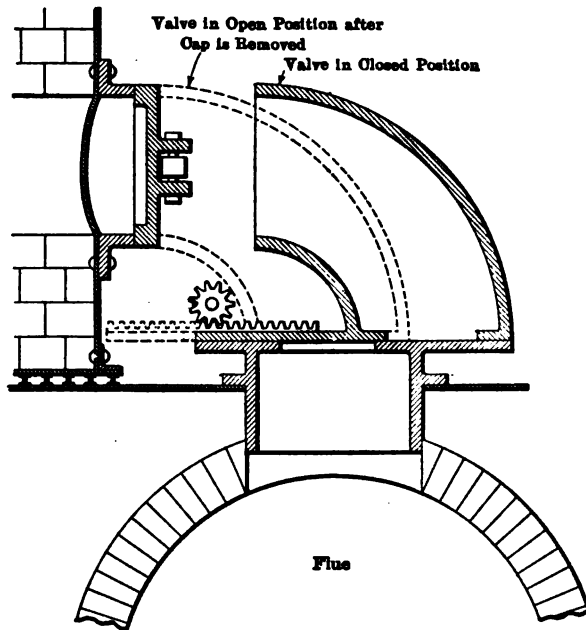


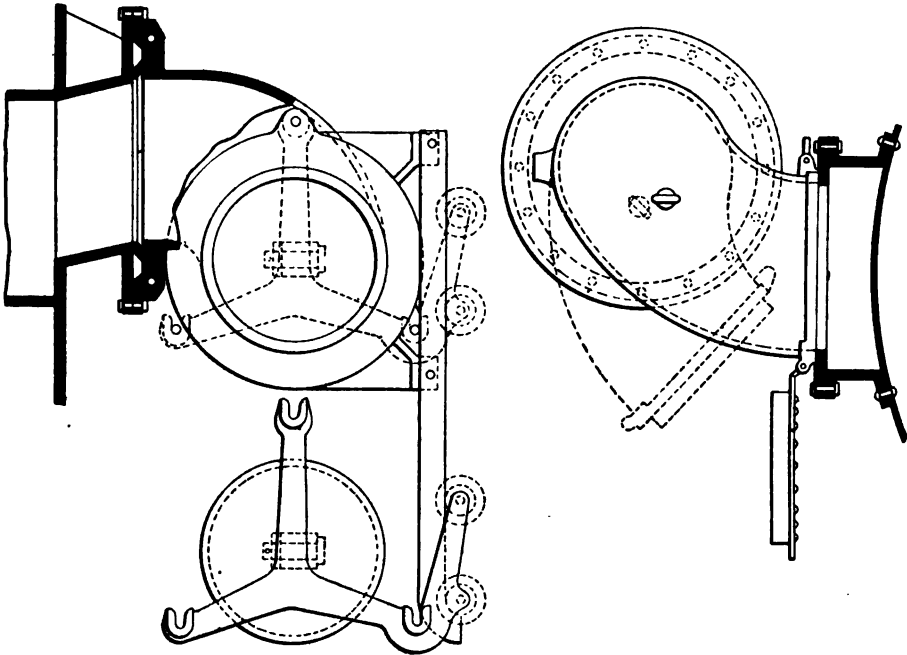
Fig. 157. Kennedy-Morrison chimney valve.

Blow-off valves. — In addition to the valves above described, there is also an air blow-off valve provided, the function of which is to blow off air left in the stove when it is taken off the furnace, since, of course, the stove must retain the furnace pressure after its outlet valve is closed. This blow-off valve is placed close to the bottom and is sometimes arranged to open quickly with a lever instead of with a screw, so that as violent a current of air as possible will blow out through it and thereby carry as much dirt as it can from the passages around the base of the stove.

The construction of this valve as used in the McClure stove is shown by Fig. 160 (page 222). It will be seen that the elbow in which the valve is mounted is arranged to swing as a whole so that this opening serves as a cleaning door as well as a blow-off.

Stove castings. — In former times the reinforcing rings around doors,

valves, burner openings, etc., were made of cast iron, but the liability of cast iron to crack when subjected to expansion and contraction stresses, and the enormous difficulty of getting at the rivets holding these to place after the stoves are bricked up has brought about the adoption of steel castings for these fittings in all good modern practice. These are somewhat more expensive in first cost but the failure of a single cast-iron fitting after the stove was in operation would involve a loss several times greater than the whole difference in cost between cast-iron and steel fittings.



Figs. 158, 159. Stenbakken chimney valve.

Packing. — It is almost unnecessary to remark that as the steel shell of the stove is exposed to the air and protected by heavy brickwork, it remains comparatively cool while the bricks are heated far beyond the red heat. Therefore, the brickwork expands several times more than the shell.

It is also characteristic of brickwork that while it expands when subjected to heat it tends not to contract to the same amount, and therefore is subject to a small but permanent growth. For this reason the shell of a stove must be considerably larger than the outside diameter of the brickwork, and in order to exert a certain amount of pressure against the bricks and keep them to place this space must be filled with some yielding material. Some constructors prefer to use for this

purpose pumice-cinder, others clay, and others again a mixture of these materials.

A similar provision must be made for the vertical expansion of the brickwork and the brick dome of the stove must be left many inches below the shell when the stove is lined. There is not the same necessity for packing material in this space as gravity tends to hold the dome to place, and this space may, therefore, be left open without

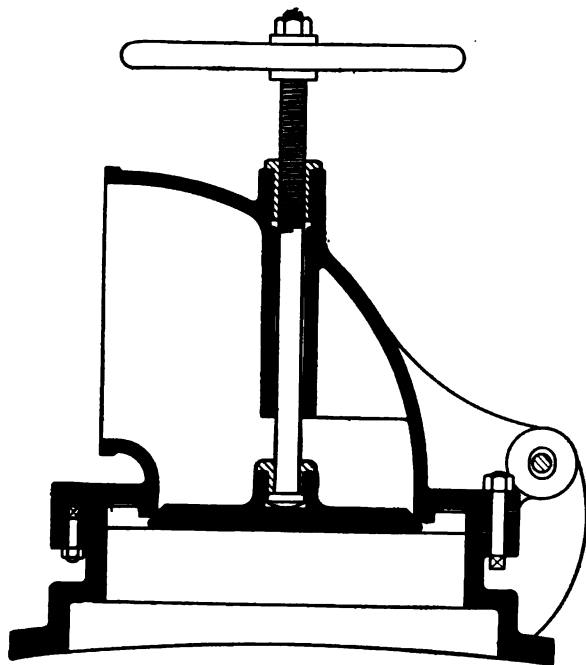


Fig. 160. Blow-off valve.

detriment. During recent years much attention has been paid to radiation losses and means for preventing them. Infusorial silica has been suggested as an insulator and should be an ideal one both on account of its tremendous insulating power and its ability to reduce its bulk under pressure.

Stack for stoves. — Mechanical draft has never been applied to hot-blast stoves so far as I know, their draft always being supplied by a stack.

The three-pass stoves each have their individual stack resting on top of them. In the case of the two-pass stoves the choice of two styles of construction is possible. One is to have a single stack for a battery of three or more stoves, the entire complement of one or two furnaces. The other alternative is to have a single stack for each stove directly connected with it.

The former practice is very much the more general, and in my judgment much to be preferred, since one large stack is undoubtedly cheaper than three or more small ones of the same total capacity. Moreover, if it be desired to cool off one stove for repairs and it be connected only with its own individual stack, no air can be drawn through it after it has cooled off a little, because there is no difference in temperature to produce a draft, although the stove may be far too hot to work in or even to enter. But if all the stoves are connected to a common stack then the chimney valve may be opened to some extent on the stove which it is desired to cool off without seriously impairing the draft of the other stoves and the cold air thus drawn through it will cool it down to a temperature at which it can be entered and repaired, in a small fraction of the time in which it would cool to the same extent without this assistance.

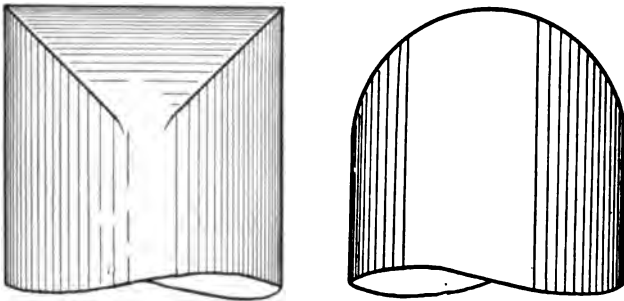


Fig. 161. Cylindrical stove top.

The domes of stoves. — In the early days many stoves were fitted with a cylindrical top as shown by Fig. 161 and this shape conforms with the mechanical requirement that all sections of the stove shall be circular in order to resist deformation, but this style of top is difficult and expensive to fit and seems particularly liable to give out along the square corners where the horizontal cylindrical surface of the top meets the vertical surface of the stove body, and stoves are now almost universally fitted with either conical or spherical tops.

The bottom and base ring of stoves. — The brickwork within bottom sheet of the stove must of necessity carry all the rest and this ring is, therefore, not capable of repair except by tearing out practically the whole lining of the stove. The principal point of corrosion about stoves appears to be where the cylindrical surface meets the bottom plate, and owing to this corrosion old stoves are liable to fail at this point sooner than almost any other, the base ring contains nearly all the openings made into the stove for cleaning-out doors, valves, etc., and its strength is thereby greatly reduced. For these reasons the bottom ring should be made of heavier material than the rest of the stove.

The stove base instead of being set down flat on a masonry foundation, as formerly, now generally rests on a set of T-rails placed close together; this carries it up off the ground and prevents corrosion to a large extent.

The joint where the bottom sheet meets the side sheets should always be made with the utmost care and almost without regard to expense. It is very doubtful if flanging is a good construction at this point. A heavy angle bent to the circle and riveted to the bottom and side sheets furnishes a better construction.

The size of the checkers. — It has been the practice in the past to make the checkers about 9" square since smaller ones could not be maintained in operation, but this practice is now beginning to undergo a change which is likely to be very rapid.

Until quite recently gas cleaning was not practiced to any considerable extent in this country, while the blast-furnace gas produced here probably carries more dirt and fine ore than that of any other country, because of the predominant portion of fine sandy ore used. This dust is carried into the stove by the gas and deposits on the brickwork which, of course, is composed largely of silica; under the intense heat to which this brickwork is exposed the iron ore constituting the larger portion of the flue-dirt is fused to the brickwork, and the wall of the combustion chamber soon becomes glazed over and finally is slagged away by this action, so much so that a false wall is always built in the combustion chamber, so that this wall may be renewed when it is burnt out without affecting the stove as a whole. In one plant, formerly under my management, we never counted that these walls would last over eight or nine months without repair, and this was due almost entirely to the slagging action of the iron ore carried by the gas.

In the checkers the conditions are not quite so bad, because the temperatures are much lower, but vast quantities of dirt settle on these in light flocculent masses, about the best non-conductor of heat which could be found. These flocculent masses greatly reduce the flow of gas through the stove and seriously impede the passage of blast through it also. Therefore, it is now necessary at intervals to take each stove off the furnace for several days, cool it down so that it can be entered, put men in the upper dome and clean these checkers by dropping through them weights suspended from a rope or chain. This is a highly laborious performance, and from the nature of the case more or less ineffective. In order to carry out this operation at all, it is necessary to lose the use of the stove for from one to two weeks under the best conditions, and during that time, unless the furnace is more than usually well provided with stove capacity, the blast is improperly heated, and the fuel economy of the furnace suffers.

In recent years it has been found that with the exercise of a certain amount of care the gas can be scrubbed practically free of these impurities at comparatively small expense. This eliminates the necessity of allowing for a coating of flue-dust from one to three inches thick on all sides of the checkers. When this is done it becomes a simple matter to use checkers six inches square which are not only as good as, but much better than checkers nine inches square when dirty gas is used, even smaller checkers are now being used.

It is obvious that the amount of heating surface which can be put into a given stove with six-inch checkers is far greater than that which can be put into it with nine-inch checkers and this means that the stove capacity needed to supply a given amount of heat to the blast may be more cheaply obtained, not only in operating cost but also in first cost, by putting in a gas-washing plant to supply clean gas, and using somewhat smaller stoves with smaller checkers. The smaller stoves so designed contain more heating surface and maintain a higher efficiency than the larger stoves under the old conditions with dirty gas.

The number of stoves per furnace. — There is no theoretical reason why one iron-pipe stove should not be sufficient for a furnace, because it is an apparatus which works continuously by the conduction of heat through metal walls exactly as a boiler does. Barring repairs it could run on indefinitely, and small furnaces in the early days were frequently run with only one stove.

As a matter of fact, especially at large furnaces, the number of stoves is increased for two reasons: First, it is difficult to build a single unit large enough to heat the quantity of blast required for a large or even a moderate-sized furnace, and at the same time to design it so as to give good control of the heat in all parts. Second, after a certain point is passed it costs no more to build the required stove capacity in two or three units than it does in one, while if there be, say, three stoves on a furnace, then, when one of them requires repairs the other two are still able to heat the blast to a very valuable extent; whereas, if only one stove be provided, when this goes down for repair the furnace must shut down because it is commercially impossible to run a furnace on cold blast.

For these reasons two or three iron-pipe stoves are commonly provided per furnace when that type is used.

In regard to the capacity and efficiency of these, little or nothing is known. As a matter of experience it can be stated that the stove illustrated in Figs. 126, 129 is capable of heating six or eight thousand feet of blast per minute up to 850° F. without such overcrowding as will destroy it too rapidly. In regard to economy and efficiency we have not even the guide of general experience to help us, because there is no way to get at the quantity of gas consumed by one of these

stoves without careful experiments on gas flow, etc., which, as far as I know, have never been conducted.

It may be safely stated that the efficiency of the Durham type of stove, that is the parallel-current type, is quite low, because the chimney gases must be discharged at a temperature of twelve hundred or more, and even with theoretically perfect combustion this involves a loss of over 50 per cent. of the heating value of the gas.

Turning now to the firebrick stove, the conditions are entirely different from what they are in the case of the iron-pipe stove, since it is impossible to get along with less than two of these, one of which is being heated up while the other is giving up its heat to the blast. Furnaces were originally operated with only two stoves of this type but this condition has long since passed away. Less than three are never contemplated, four is only ordinary good practice, and five have been installed with extremely satisfactory results at some plants.

The reason for the increased number of stoves is twofold. First, to have one in reserve, or at least be in a position to spare one for repairs without crippling the plant; second, because the heating of the blast by this process is an intermittent operation, and therefore the temperature of the blast fluctuates with the condition of the stove. When the stove is first put on it has been heated up to a high temperature, which falls as it gives up its heat and the blast temperature is therefore constantly falling.

When only two stoves are provided these variations are so great as to cause serious irregularities in the work of the furnace. By adding a third stove and burning the gas so as to give them what steel men know as a "soaking heat," their temperature falls much less rapidly while they are on blast. The fact that the relative time on gas is doubled while the time on blast remains the same contributes much to this result. This greatly reduces the irregularities due to the intermittent action of the apparatus.

But, when one stove requires to be taken out of service for repair the furnace is then thrown back onto the two-stove condition. This cuts down the heating surface to two-thirds and reduces the average blast temperature materially as well as making serious irregularities in the temperature curve. Therefore, in order always to have the benefit of three stoves, four must be provided; this gives three hours on gas for one on blast, which is a step better than the condition existing when three stoves are used.

Four stoves introduce the possibility of operating along a somewhat different plan, with the object of eliminating inequalities of blast temperature still more. This plan is to blow through two stoves simultaneously, leaving them each on blast one hour, but changing them at alternate half hours. This reduces the time of the stove on gas

to one-half the total time, but halves the amount of heat taken out of it at any period. It involves somewhat more work for the stove tender, but practically halves the variations of blast temperature from maximum to minimum.

Here, again, we come to the necessity of occasional repairs necessitating a return to three-stove conditions, and this has caused many operators to consider five stoves a good investment, because then four stoves can always be maintained in operation, even when one is being repaired, and when all five are available each one can be left on gas for three hours and on blast for two hours, with still better results in eliminating irregularities in the blast temperature and maintaining a high average temperature without driving the stove too hard when it is on gas.

It will be seen, then, that the number of firebrick stoves to be supplied per furnace depends to some extent upon natural conditions, which we cannot control, and that if the best results are to be attained under present conditions, not less than four must be supplied. But, since the introduction of clean gas at some plants, it has been found that the stoves do not need to come off during an entire blast for either cleaning or repair, and this fact in addition to the increased economy and greater heating surface attainable as a result of clean gas have a tendency to reduce the number of stoves required, and it may well be doubted if five stoves will in future be installed at plants originally designed to use clean gas. It may be that the number required will fall to three.

Equalizing the blast temperature. — The proposal has been made by several blast-furnace engineers and operators to apply an equalizer to remove the objectionable peaks from the charts of blast temperature, and several of these apparatus have been built. One of the few in this country was that built by John S. Kennedy and the late John M. Hartmann at the Musconetcong furnace, Stanhope, N.J., which has been most successful in operation.

This apparatus is practically a small stove without combustion chamber or valves, filled with very small checker work through which the blast passes on its way from the stoves to the furnace. When the blast is very hot from putting on a fresh stove the excess heat above the average is given up to the checker work in which it remains stored until the temperature of the blast falls below the average, owing to the cooling of the stove, when this stored surplus flows out and makes up the deficiency.

Mr. Kennedy has told me that this apparatus smoothed down the "saw teeth" on the blast temperature charts so that the maximum temperature difference for long periods continuously was less than twenty-five degrees. Without such an apparatus the drop in temper-

ature between putting on and taking off a stove will run from 50° to 150°, depending on the number of stoves and how they are handled.

Another method for obtaining a uniform blast temperature is by the use of a cold-wind mixing valve. This valve is located on the hot-blast main into which it opens and is connected with a branch from the cold-blast main. By opening this valve cold blast direct from the engine can be admitted into the hot-blast main, thus cutting down the temperature of the blast by admitting a considerable quantity of this cold air as a fresh stove is put on the furnace and gradually diminishing this quantity down to nothing, at or near the time when the stove comes off.

By this means the blast temperature may be maintained uniform, but this method is open to two objections: First, that the uniform blast temperature is, in that case, the lowest temperature furnished by the stoves instead of the average, and, second, the equalization depends wholly on the skill and fidelity of the stove tender, and if done properly requires such frequent attention by him as to militate against his assisting at other work.

Attempts have been made to provide an automatic control of this valve, which would relieve the stove tender of the duty of regulating it and would give perfect equalization of the blast temperature, but so far as known to me none of the apparatus designed for this purpose is now in regular commercial use.

The size and heating surface of stoves.—Practice in regard to these matters in the past has been based on general experience and the belief of the furnace man or engineer that stoves of about such a size would be sufficient to supply the hot blast for a given furnace. It is not a rule but it seems to be according to general practice that the diameter of the stove shall be about the same as the bosh diameter of the furnace, and that its height shall be as a minimum that of the furnace and from that up to twenty or twenty-five per cent. more.

Until recently but little attention was paid to the quantity of heating surface furnished per foot of stove height, but there is evidence that this condition is passing and that within a few years stoves will be bought on their heating surface, practically as boilers are to-day. This has been impossible except in the most general way in American practice until now, because the hard driving of American furnaces, combined with the enormous percentage of extremely fine ore used at seventy-five per cent. of them, has made an exceedingly dirty gas, and this dirt depositing on the checkers in the way already described has reduced the efficiency of the stove in proportion to the extent in which it has been allowed to accumulate, so that stoves kept clean and under good management at one plant are capable of heating a given quantity of blast to a much higher temperature than similar stoves at another plant where they are not properly cleaned.

To a large extent these conditions have been past control and absolutely past all calculation. General experience has, therefore, been practically the only guide. With the introduction of primary cleaning for all the gas, that which goes to the stoves will be in vastly better condition than it is now, the stoves will stay clean for far longer periods and will have not only a higher but a more definite efficiency.

The advantages of smaller checkers already pointed out, which become available under those conditions, will cause competition among stove builders to give the maximum amount of heating surface per stove, and we shall gradually reach the place where the capacity and economy of stoves are as well understood as that of any other apparatus around the plant, a condition which certainly does not exist at the present time.

There has been in recent English and American literature little or nothing on the hot-blast stove from the operating point of view, but in December, 1912, Mr. A. N. Diehl published before the Engineers' Society of Western Pennsylvania a very valuable paper giving the results of long and careful investigation of the subject, and in October, 1913, in a discussion of the subject of gas cleaning before the American Institute of Mining Engineers he contributed additional data on the subject.

His tables I and II (pages 230 and 231) from the first-mentioned paper are reproduced here and will repay careful study.

With clean gas the efficiency of the stove is raised considerably, according to Mr. Diehl's later figures, from 56 per cent. to 64 per cent. This is not a decrease of 8 per cent., but of $12\frac{1}{2}$ per cent. ($8 \div 64$) in the gas consumption of the stove and, what is much more important, it brings with it the possibility of obtaining higher blast temperatures with a given equipment of stoves and by this means reducing the coke consumption of the furnace.

Table I shows the advantage of having a sufficient amount of heating surface for the given conditions, and as the use of clean gas makes permissible the use of smaller checkers and thereby increases the heating surface, it may be said that the effect of clean gas is cumulative in its influence on stove design and operation. The best practice as brought out by Mr. Diehl's paper and its discussion favors the use of not less than four and preferably five square feet of heating surface per cubic foot of blast blown per minute measured by piston displacement. When four stoves are used this would mean from one to one and a quarter square feet of heating surface per stove for each cubic foot of blast blown per minute.

This will obviously vary to some extent with the conditions. When high heats are regularly required, as with the use of lean and refractory ores, more heating surface should be provided than with soft and

TABLE NO. 1
EXCERPT FROM STOVE TESTS

Stove	Heating surface sq. ft.	Volume of brickwork, cu. ft.	Fuel gas.	Volume of fuel gas per min.	Calorific value of fuel gas B.T.U.	Blast per min. cu. ft.	Temperature flue gas.			Temperature blast.			Heat balance.		Stove on gas blast mins.	Stove on blast mins.	Flue gas per cent.	
							Max.	Min.	Avg.	Max.	Min.	Avg.	Absorbed blast.	Lost in flue gas Per cent.			CO	O ₂
1 Center Comb.	49865	20831	Clean	4282	108.5	36328	680	370	630	1555	1270	1418	63.37	17.53	172	58	0.47	2.29
2 3-Pass				4527	105.8	35742	720	565	670	1600	1360	1360	62.24	17.40	179	60	0.12	1.18
3				3847	99.0	36542	660	540	619	1440	1235	1328	61.59	17.55	180	60	2.40	
4				3386	104.4	36106	640	540	614	1335	1135	1231	66.02	16.87	181	59	0.11	2.94
Average				4010	104.4	36130	685	554	633	1487	1250	1359	63.30	17.34	178	59	0.77	1.65
1 Center Comb.	39220	17974	Clean	3338	104.3	40030	475	370	442	1310	800	957	51.75	24.54	175	58	0.80	8.00
2 2-Pass				3523	94.1	33905	670	495	625	1440	1035	1200	53.26	28.70	171	50	0.80	6.50
3				3497	102.1	37678	700	490	615	1200	850	1051	44.03	34.17	179	50	0.80	9.70
4				3548	104.5	40590	659	500	624	1340	1035	1156	61.24	20.14	172	61	0.90	4.60
5				3489	94.3	40580	525	420	441	1451	1036	1201	64.48	19.28	196	64	0.80	2.90
6				2905	99.7	34343	680	485	612	1310	970	1076	66.73	13.16	181	60	1.10	2.50
7				3156	96.6	39632	535	430	489	1340	1010	1162	65.26	12.33	190	57	2.00	
8				3092	99.2	39852	525	420	476	1470	1030	1149	61.98		182	57	3.30	
Average				3368	99.3	37951	595	451	540	1358	969	1094	58.60	20.40	181	57	1.26	4.27
1 Center Comb.	39220	17974	Dirty	4120	103.2	39149	860	610	788	1450	1015	1163	47.13	29.50	200	66	0.80	5.60
2 2-Pass				4735	94.9	39000	915	650	819	1460	1000	1203	54.20	24.76	190	66	0.80	0.60
3				4241	105.0	38735	960	620	864	1410	990	1179	50.68	24.20	169	51	0.80	1.00
4				3898	99.4	38780	930	600	813	1425	1000	1148	56.97	24.95	149	51	0.80	
Average				4248	100.6	38916	916	620	821	1336	1001	1176	54.24	25.85	177	59	0.75	1.80
1 Side Comb.	30725	7494	Dirty	2832	79.6	35802	510	340	457			1047	42.30		179	30	0.82	4.47
2 2-Pass				3114	84.1	35802	550	295	475			982	59.3		174	53	0.24	1.56
3				3061	82.6	36022	430	320	377			944	57.90		157	45		
4				2448	83.1	35802	730	305	567			974	64.90		196	49	0.26	2.54
5				2772	75.8	35802	540	390	478			891	62.30		173	51		
6				3524	83.2	36400	655	495	600			986	56.10		180	54		3.58
7				3887	87.9	36400	690	450	606			990	58.20		165	60	0.17	1.77
Average				3091	82.7	35990	583	370	509			977	57.30		175	49	0.21	1.99

NOTE: Side Combustion Stove as above, volume of brickwork is for checkers only.
Center Combustion Stoves, Duquesne.
Side Combustion Stoves, Foreign.

TABLE NO. 2
SHOWING HEAT LOSSES IN STOVE PRACTICE DUE TO INEFFICIENT COMBUSTION OF FUEL GAS

Test No.	Volume of fuel gas per min. cu. ft. 1	Volume ratio fuel gas to fuel gas. 2	Volume of fuel gas per min. cu. ft. 3	Calorific value of fuel gas B.T.U. 4	Average temp. of fuel gas. 5	Flue gas Per cent.		Heat losses in flue gas due to		Volume of CO in flue gas per min. cu. ft. 10	Volume of excess air in flue gas cu. ft. 11*	Total heat losses due to CO and excess air. Per cent. 12	Coke eqv. heat losses per day per lb. 13†	Coke eqv. heat losses per day per lb. 14‡
						CO 6	O ₂ 7	CO 8	O ₂ 9					
1	4282	1.993	8534	106.5	630	0.47	2.29	2.46	2.15	30.11	862.51	4.61	105.3	7582
2	4827	1.718	7777	105.8	670	0.12	1.18	0.53	1.07	9.33	416.31	1.60	37.7	2714
3	3847	1.540	5824	99.0	619	2.40	2.94	11.61	2.70	142.18	849.91	11.61	217.5	15660
4	3386	1.849	6260	104.4	614	0.11		0.50		6.89		3.20	55.5	3998
Average	4010	1.775	7049	104.4	633	0.77	1.65	3.77	1.97	47.12	709.57	5.24	104.0	7763
1	3838	2.928	11238	104.3	442	0.60	8.00	4.70	8.31	67.43	4138.25	13.01	256.1	18439
2	3523	2.000	7363	94.1	625	0.60	6.50	5.15	7.53	44.18	2182.09	12.68	207.3	14925
3	3497	2.574	9001	102.1	615	0.80	9.70	8.31	12.72	72.00	3998.68	21.03	369.1	26575
4	3548	2.078	7373	104.5	624	0.90	4.60	5.37	4.54	66.36	1461.72	9.91	221.7	15962
5	3489	1.757	6130	94.3	612	0.80	2.90	4.52	2.60	36.78	761.72	7.12	115.2	8294
6	2905	1.805	5063	99.7	441	1.10	2.90	6.22	1.24	55.69	471.92	7.36	110.2	7984
7	3156	1.281	4043	96.6	489	2.00		9.39		80.86		9.39	140.8	10137
8	3092	1.558	4817	99.2	476	3.30		14.34		158.96		14.34	216.6	15595
Average	3368	2.134	6853	99.3	540	1.26	4.27	7.12	4.62	71.53	1626.54	11.87	204.6	14733
1	4120	2.415	9950	103.2	798	0.80	5.60	5.32	8.48	79.60	2473.38	13.80	288.5	20772
2	4735	1.864	8731	94.9	819	0.80	0.60	4.11	0.28	69.85	83.74	4.39	97.0	6984
3	4241	1.731	7341	105.0	864	0.80	1.00	3.75	0.80	58.73	210.62	4.55	100.0	7200
4	3698	1.654	5447	99.4	813	0.60		2.85		32.68		2.85	54.2	3862
Average	4248	1.911	7867	100.6	821	0.75	1.80	4.01	2.39	60.21	691.98	6.40	134.9	9712
1	2832	1.834	5194	79.6	457	0.82	4.47	6.23	3.71	42.59	1008.16	9.94	110.4	7935
2	3114	1.546	4814	84.4	475	0.24	1.56	1.45	1.09	11.55	330.72	2.54	32.8	2362
3	3061	1.718	4205	82.6	377	0.26	2.54	2.08	2.92	10.93	484.42	5.00	42.6	3067
4	3448	1.718	4205	83.1	369									
5	3572	1.778	6266	79.8	478		3.58		3.16	1072.12		3.16	58.0	4176
6	3552	1.778	600	83.2	600	0.17	1.77	1.01	1.60	10.40	491.28	2.61	43.7	3146
7	3867	1.574	6118	87.9	606									
Average	3091	1.690	5319	82.7	509	0.21	1.99	2.15	2.49	15.07	757.45	4.65	57.5	4137

* Col. No. 11 — Over and above that required to oxidise the CO present in the flue gas.
† Col. No. 13 — Per stove per hour and based on coke having a calorific value of 12,200 B. T. U. per lb. as received.
‡ Col. No. 14 — Based on four stoves per furnace, or 72 stove hours per day on gas and 24 stove hours per day n blast.
Note: All gas volumes and calorific values are at Standard Conditions, 62 F. and 30 in. Hg.
Above test Numbers correspond to those given in Table No. 1.

reducible ores which ordinarily do not need such high heats. On the other hand, when there is no use for the surplus gas it may be better to save in the size of the stoves and burn the gas less economically in them to get the desired heat.

Since this section was originally written there have appeared accounts of recent experiments in Germany in which the heat imparted to the stove was greatly increased by increasing the velocity of the gas through it, first by an air jet in the combustion chamber and in the later experiment by use of a fan to increase the draft. It is claimed that by the use of this system so much heat can be stored in each stove that only two are needed per furnace.

The accounts are too incomplete, and it is too early in the development to say what the final result will be, but with the vast improvement made in the operating conditions of stoves by clean gas there is no doubt that many improvements will follow and that increasing the velocity of the gas and blast through the checkers is one of the best ways to increase the rate of heat transmission.

As the efficiency of stoves increases it is very likely that fans will be used to provide draft for them for the reason that high efficiency can only come with low stack temperatures. Chimneys only provide good draft with fairly high temperatures and with a consequent waste of much heat. Therefore, it seems natural to expect that this conflict of requirements will be solved by the use of a fan whose performance becomes increasingly better as the temperature falls and which gives absolute control of conditions of draft, rate of combustion, etc.

The limit of possibility in reducing stove capacity is set by the amount of heat it is possible to store in a given weight of brickwork with a reasonable increase in its temperature, for if too great a drop in the temperature of the brickwork be necessary more gas is required and this limitation must be carefully considered in any plan for reducing the stove capacity.

Within the last year or two where clean gas is available stove heating surface is increased by making the side of the checker bricks wavy instead of straight. No detailed results of this practice are available.

Three stoves with clean gas and high gas velocity may easily be better than four without those advantages, but whether it will ever pay to reduce the number of stoves below three may well be doubted until overwhelming proof is offered.

CHAPTER VI

THE CONSTRUCTION OF THE BLAST-FURNACE STACK

The conditions to be met. — In the construction of the blast furnace the conditions to be met are diverse and to some extent conflicting. The efforts to meet them have been almost innumerable, and the most varied types of construction have been used for almost all portions of the furnace. An outline of the requirements to be met will assist in explaining the types of construction used.

Resistance to temperature. — Resistance to temperature is necessary to some extent throughout the furnace, but particularly in the hearth and bosh. The temperatures in these regions in the days of cold-blast furnaces were moderate, probably around 2200° to 2400° F., and were resisted with some success even by natural refractories such as sandstone, which was sometimes used for the bottom and for the lining of the hearth and bosh of furnaces, even in coke practice, within little more than a generation.

But with the development of the furnace in the direction of greater output, and the more accurate control of the quality of the metal produced, the requirements have steadily grown more severe. Temperatures in the hearth and bosh in coke practice now probably range from 2500° to 2800°, these being the temperatures of the iron and slag as they come from the furnace, but it is almost certain that even higher temperatures exist around the tuyère zone. Probably 3000° is not far from the working temperature prevailing in that zone in many furnaces. This approaches the temperature at which all materials lost a great portion of their resistance. If they do not melt they soften and are easily deformed or abraded.

Resistance to chemical action. — The lining of the blast furnace is probably exposed to more diverse chemical conditions than that of any other apparatus in industrial use. Iron itself, when molten, particularly before it is completely carbonized, is exceedingly active chemically and will dissolve or react with almost anything with which it comes in contact, especially substances in their elementary condition.

In the early days when sandstone was used as a refractory, slags used in coke practice were relatively neutral — that is, they were what would now be called very acid. The requirements were then not nearly so severe in the matter of desulphurization, and as a consequence not much more lime was added than enough to make a fusible slag. But

TABLE NO. 1
EXCERPT FROM STOVE TESTS

Stove	Heating of brick surface, sq. ft.	Volume of brickwork, cu. ft.	Fuel gas.	Volume of fuel gas per min.	Calorific value of fuel gas, B.T.U.	Blast per min. cu. ft.	Temperature flue gas.			Temperature blast.			Heat balance.		Stove on gas blast mins.	Stove on gas blast mins.	Flue gas per cent.	
							Max.	Min.	Avg.	Max.	Min.	Avg.	Absorbed blast.	Lost in flue gas.			CO	O ₂
1 Center Comb.	49865	20831	Clean	4282	108.5	36328	680	370	630	1555	1270	1418	63.37	17.53	172	58	0.47	2.29
2 3-Pass				4527	105.8	35742	720	565	670	1600	1360	1462	62.24	17.40	179	60	0.12	1.18
3				3947	99.0	36542	640	540	619	1440	1235	1328	61.59	17.55	180	60	2.40	2.94
4				3386	104.4	36109	640	540	614	1335	1135	1231	66.02	16.87	181	59	0.11	
Average				4010	104.4	36130	685	554	633	1487	1250	1359	63.30	17.34	178	59	0.77	1.65
1 Center Comb.	39220	17974	Clean	3338	104.3	40030	475	370	442	1310	800	957	51.75	24.54	175	58	0.80	8.00
2 2-Pass				3523	94.1	33905	670	495	625	1440	1035	1200	53.26	28.70	171	52	0.80	6.50
3				3497	102.1	37678	700	490	615	1200	850	1051	44.03	34.17	179	50	0.80	9.70
4				3548	104.5	18590	659	500	624	1340	1035	1156	61.24	20.14	172	61	0.90	4.60
5				3489	94.3	40580	525	420	441	1451	1036	1201	64.48	19.28	199	64	0.80	2.90
6				2805	99.7	34343	680	485	612	1310	970	1076	66.73	13.16	181	60	1.10	2.50
7				3156	96.6	39632	535	430	489	1340	1010	1162	65.26	12.33	190	57	2.00	
8				3092	99.2	38852	525	420	476	1470	1030	1149	61.98		182	57	3.30	
Average				3368	99.3	37951	595	451	540	1358	969	1094	58.60	20.40	181	57	1.26	4.27
1 Center Comb.	39220	17974	Dirty	4120	103.2	39149	860	610	788	1450	1015	1163	47.13	29.50	200	66	0.80	5.60
2				4735	94.9	39000	915	650	819	1460	1000	1203	54.20	24.76	190	66	0.80	0.60
3				4241	105.0	38735	960	620	864	1410	990	1179	50.68	24.20	169	51	0.90	1.00
4				3898	99.4	38780	930	600	813	1425	1000	1148	56.97	24.95	149	51	0.60	
Average				4248	100.6	38916	916	620	821	1336	1001	1176	54.24	25.85	177	59	0.75	1.80
1 Side Comb.	30725	7494	Dirty	2832	79.6	35802	510	340	457			1047	42.30		179	30	0.82	4.47
2 2-Pass				3114	84.1	35302	560	295	475			982	59.3		174	53	0.24	1.56
3				3061	82.6	36022	430	320	377			944	57.90		157	45		
4				2448	83.1	35802	730	305	567			974	64.90		196	49	0.26	2.54
5				2772	75.8	35802	540	390	478			891	62.30		173	51		
6				3524	83.2	36400	655	495	600			986	56.10		180	54		3.58
7				3887	87.9	36400	690	450	606			990	58.20		165	60	0.17	1.77
Average				3091	82.7	35990	583	370	509			977	57.30		175	49	0.21	1.99

NOTE: Side Combustion Stove as above, volume of brickwork is for checkers only.
Center Combustion Stoves, Duquesne.
Side Combustion Stoves, Foreign.

TABLE NO. 2
SHOWING HEAT LOSSES IN STOVE PRACTICE DUE TO INEFFICIENT COMBUSTION OF FUEL GAS

Test No.	Volume of fuel gas per min. cu. ft. 1	Volumetric ratio of fuel gas to fuel gas. 2	Volume of fuel gas per min. cu. ft. 3	Calorific value of fuel gas B.T.U. 4	Average temp. of fuel gas. 5	Flue gas Per cent.		Heat losses in flue gas due to		Volume of CO in flue gas per min. cu. ft. 10	Volume of excess air in flue gas cu. ft. 11*	Total heat losses due to CO and excess air. Percent. 12	Coke eqv. of heat losses, per hour. lb. 13†	Coke eqv. heat losses per day per ton. lb. 14‡
						CO 6	O ₂ 7	CO 8	O ₂ 9					
1	4282	1.993	8534	108.5	630	0.47	2.29	2.46	2.15	30.11	862.51	4.61	108.3	7582
2	4527	1.718	7777	105.8	670	0.12	1.18	0.53	1.07	9.33	416.31	1.60	37.7	2714
3	3847	1.540	5924	99.0	619	2.40	2.94	11.61	2.70	142.18	949.91	11.61	217.5	15660
4	3386	1.849	6260	104.4	614	0.11		0.50		6.89		3.20	55.5	3996
Average	4010	1.775	7049	104.4	633	0.77	1.65	3.77	1.97	47.12	709.57	5.24	104.0	7763
1	3838	2.928	11238	104.3	442	0.60	8.00	4.70	8.31	67.43	4136.25	13.01	258.1	18439
2	3523	2.000	7363	94.1	625	0.60	6.50	5.15	7.53	44.18	2182.09	12.68	207.3	14925
3	3497	2.574	9001	102.1	615	0.80	9.70	8.31	12.72	72.00	3998.68	21.03	389.1	28575
4	3548	2.078	7373	104.5	624	0.90	4.60	5.37	4.54	66.36	1461.72	9.91	221.7	15962
5	3489	1.757	6130	94.3	612	0.80	2.90	4.52	2.60	36.78	761.72	7.12	115.2	8294
6	2805	1.805	5063	99.7	441	1.10	2.50	6.22	1.24	55.69	471.92	7.36	110.2	7884
7	3156	1.281	4043	96.6	489	2.00		9.39		80.86		9.39	140.8	10137
8	3092	1.558	4817	99.2	476	3.30		14.34		158.96		14.34	216.6	15595
Average	3368	2.134	6853	99.3	540	1.26	4.27	7.12	4.62	71.53	1026.54	11.87	204.6	14733
1	4120	2.415	9850	103.2	768	0.80	5.60	5.32	8.48	79.60	2472.38	13.80	288.5	20772
2	4735	1.871	8731	94.9	819	0.80	0.60	4.11	0.28	69.85	83.74	4.39	97.0	6984
3	4241	1.731	7341	105.0	864	0.80	1.00	3.75	0.80	58.73	210.62	4.55	100.0	7200
4	3898	1.654	5447	99.4	813	0.60		2.85		32.68		2.85	54.2	3892
Average	4248	1.911	7867	100.6	821	0.75	1.80	4.01	2.39	60.21	691.98	6.40	134.9	9712
1	2832	1.834	5194	79.6	457	0.82	4.47	6.23	3.71	42.59	1008.16	9.94	110.4	7935
2	3114	1.546	4814	84.1	475	0.24	1.56	1.45	1.09	11.55	330.72	2.54	32.8	2362
3	3061	1.377	3777	82.6	377									
4	2448	1.718	4205	83.1	569	0.26	2.54	2.08	2.92	10.93	484.42	5.00	42.6	3067
5	2772	1.718	4205	83.1	478									
6	3524	1.778	6266	83.2	600		3.58		3.16	10.40	1072.12	3.16	58.0	4176
7	3887	1.574	6118	87.9	606	0.17	1.77	1.01	1.60	10.40	491.28	2.61	43.7	3146
Average	3091	1.690	5319	82.7	509	0.21	1.99	2.15	2.49	15.07	757.45	4.65	57.5	4137

* Col. No. 11 — Over and above that required to oxidize the CO present in the flue gas.
† Col. No. 13 — Per stove per hour and based on coke having a calorific value of 12,200 B. T. U. per lb. as received.
‡ Col. No. 14 — Based on four stoves per furnace, or 72 stove hours per day on gas and 24 stove hours per day n blast
Note: All gas volumes and calorific values are at Standard Conditions, 62 F. and 30 in. Hg.
Above test Numbers correspond to those given in Table No. 1.

modern practice it is never less than 1000 ft. per minute, and more probably double that. This gas is necessarily filled with fine particles of material from the stock, which is in a constant state of agitation due to its descent, so that the fines are swept out of it almost as chaff is separated from wheat. These fines are picked up and carried by this great volume of gas moving at this high velocity. Most of the particles impinge on the solid stock, but many of them strike the furnace walls and exert thereon the action of the familiar sand blast. In this case also we must remember that the resisting material, at least in the lower regions of the furnace, is softened by heat so that much of its resistance is gone, and it becomes evident that we have here a form of destructive energy whose effects cannot be ignored.

Resistance to pressure. — It is absolutely necessary that the furnace be gas-tight in the same way, and as nearly as possible to the same extent, that a good boiler is steam-tight. The pressures, it is true, are not as high as modern boiler pressures, but they range from 10 to 30 lbs. per square inch in modern practice, probably averaging in Lake ore practice around 15 lbs.

The effect of pressure in promoting reaction, especially when gases are concerned, and its effect in giving density and carrying power to the gas currents, are probably factors in the situation, but the principal point is that if this pressure be not resisted at every point gas will find the weak spot, and, traveling through it will carry heat and chemical action to assist the destructive effect of the pressure. The pressure-resisting quality of the structure comes from the steel shell outside the lining, but this is quickly destroyed if the conditions prevailing within the furnace proper strike it, and with its destruction the whole structure fails. For this reason resistance to pressure is one of the prime conditions to be met.

The constructions adopted. — Had the builders of those tiny furnaces which dotted the Central Eastern states in the first half of the last century been shown these formidable specifications before having practical knowledge of the subject they would undoubtedly have thrown up their hands and ceased all efforts to meet such apparently impossible conditions. But, as a matter of fact, they had not the disadvantage of this knowledge, for disadvantage in their case it would have been, since the practice to which they were accustomed involved difficulties constituting only a fraction of those outlined above. This was due to the lower temperatures and the lower rate of driving, with its reduction of abrasion both by gas and by stock, and perhaps most important of all they did not dream of such pressures as we now consider right and proper.

In happy ignorance, therefore, of the conditions which their successors would have to meet, they built stacks of stone, truncated pyra-

mids, one side of the base almost as long as the stack was high. In the earliest days all these were built, as I have already described, against and into a hill. Only one tuyère was used. No distinction was made between supporting structure and lining. The stack was simply a truncated pyramid 20 to 40 ft. high, with a hole some 6 or 8 ft. in diameter through it, hardly different from a square chimney with a round flue, except of more squatty proportions. In one side was an archway into the stonework which gave access to the single tuyère, the forehearth which I have previously described, and the tapping hole.

This simple pile of masonry resisted the pressure of the blast, the heat of the combustion, the abrasive action of the stock and the chemical action of its heterogeneous contents.

The gradual increase in output from those days to our own brought changes in construction, and these in turn permitted greater outputs which again required other changes of construction, and so, with each successful step helping toward the next, by slow, painful and costly progress we have passed from those primitive conditions to those prevailing to-day.

Two of the earliest changes were the substitution of firebrick for the lining of the stack and the provision of an archway in each side of the structure with a tuyère in each arch instead of only one. More probably in many cases three of the arches were used for tuyères; in the fourth the tuyère was left out in order to make room for the forehearth, tapping hole, etc. Gradually, as the proper shape of the furnace was evolved, the hearth structure became separated at the base from the piers of masonry which supported the whole stack, and finally it became evident that it was desirable to increase the distance between these so as to provide greater access to all portions of the hearth. In course of time also the stone stack with its binders of hewn timbers gave way to a brick stack banded with flat bands like a tank, the structure passing from square to round in its exterior shape, the lining being of firebrick and fully differentiated from the stack proper.

About 1860 this structure was superseded at one of the Lake Champlain furnaces by a shell riveted up of plate iron standing on cast iron columns, and lined with firebrick, the prototype of the structure used to-day.

The photograph of a modern furnace is shown by Fig. 162 (page 238). The stack is at the right. A section drawing of a different but similar furnace, with its hoist is shown in Fig. 163 (page 239).

It will be seen that there is a foundation of concrete 13 ft. below the ground level and 39 ft. in diameter, upon which the whole structure rests. An annular foundation of brickwork upon this supports the bases of the columns, ten in number, each 25 ft. high and $2\frac{1}{2}$ in. thick.

Upon these columns rests a heavy ring of structural material better shown in detail in Fig. 164 (page 240), and to this "mantle" is riveted the shell of $\frac{3}{4}$ -in. steel plate, 36 ft. in diameter at the bottom and 23 ft. 11 in. in diameter at the top. This shell is riveted up with the same class of workmanship as that used in the best steam boilers. Within this shell is the brickwork about 4 ft. thick at the level of the mantle and maintaining nearly this thickness all the way to the top. Below

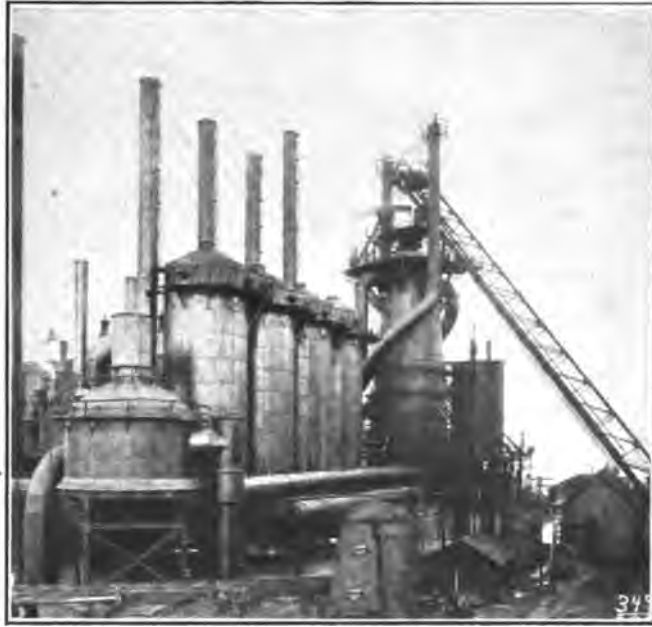


Fig. 162. Modern blast furnace stack with stoves and dustcatchers.
Built by William B. Pollock Company.

the top of the mantle the brickwork is thinner down to the tuyères and then below the tuyères thicker again, finally uniting with the furnace bottom, which consists of some 8 or 9 ft. of solid firebrick work on the concrete foundation.

This structure is, in broad outlines, typical of the standard construction of to-day, but the variations of detail are almost as numerous as the individual furnaces. It is impossible to describe all these variations individually, but by dividing the furnace into zones we may deal in some detail with the conditions to be met and the approved forms of construction in each. The zones in which the furnace should be divided for this purpose are the hearth and bottom, the tuyère zone, the bosh, the shaft, and the top.

The hearth and bottom. — The necessity of resistance to chemical action for the furnace as a whole has been briefly described above.

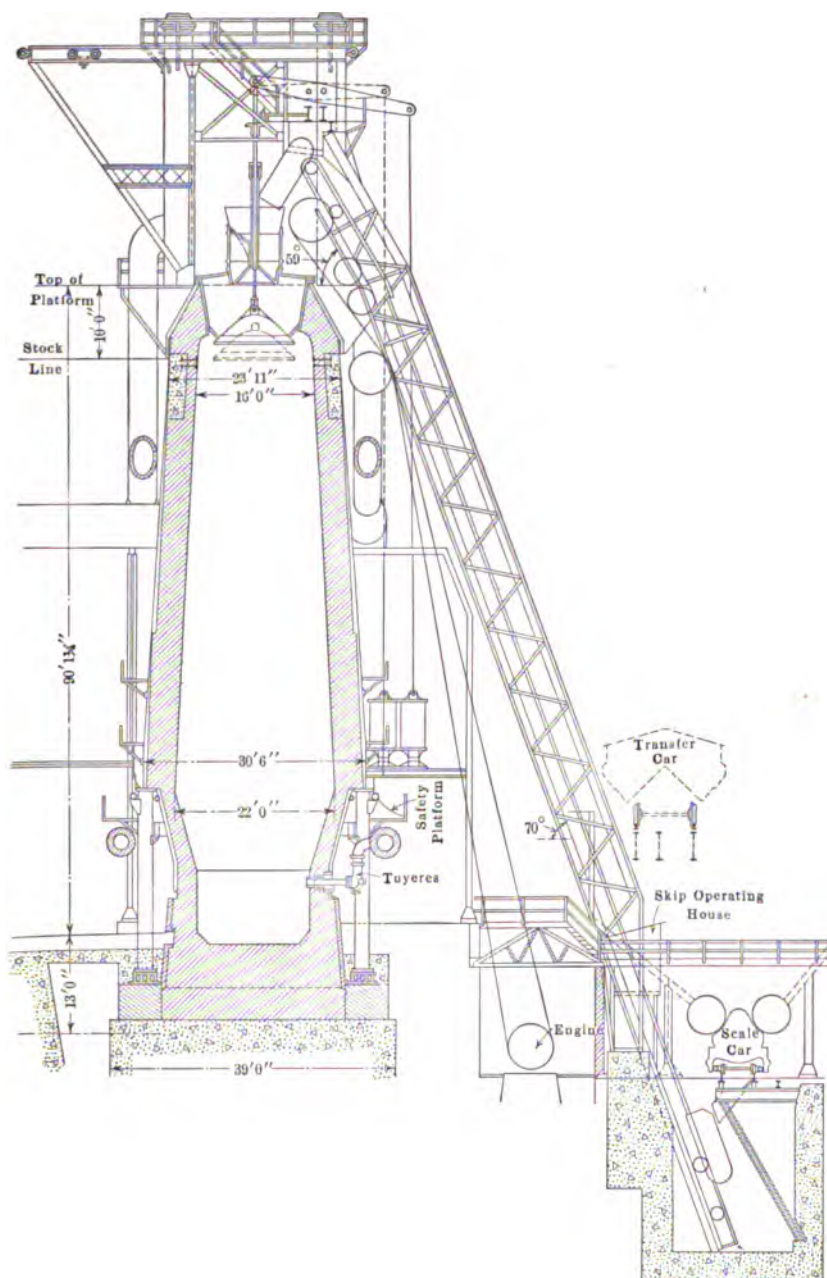


Fig. 163. Vertical section of "A" furnace, Bethlehem Steel Company.

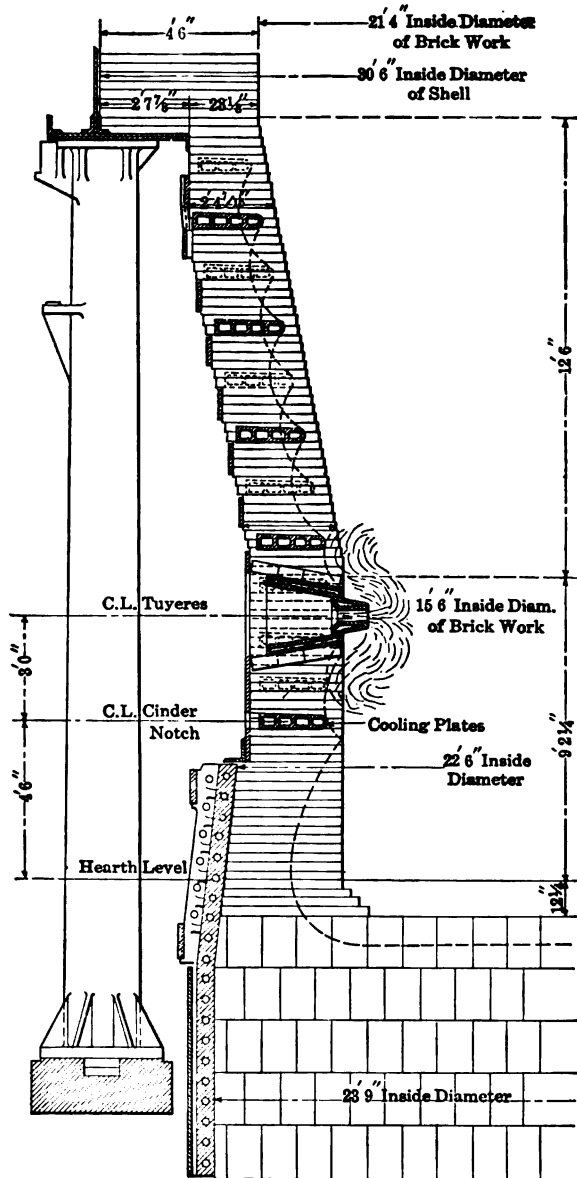


Fig. 164. Hearth and bosh of Inland Steel company's "B" furnace.

This is particularly necessary in the hearth and bottom because these actions are the most intense in that region and because the consequences of failure of these structural parts are so disastrous.

The hearth of a furnace just before the cast time contains normally 60 to 80 and may readily contain 150 tons of molten iron and 20 to

40 tons of slag. The effect of pressure in intensifying chemical action has already been mentioned and in the hearth this condition is aggravated by the fact that the pressure due to the depth of metal and of slag on top of it, is added to the pressure of the blast which, of course, is highest at the tuyères. We may have, therefore, a depth of 7 or 8 ft. of metal with 2 or 3 ft. of slag laying over it, exerting a pressure of 3 lbs. per square inch for each foot in depth of iron, and about 1 lb. for each foot in depth of cinder, so that we can easily have a liquid pressure of 25 or 30 lbs. in the bottom of the furnace in addition to the 15 lbs. of blast pressure in one properly working or perhaps 30 lbs. in one working irregularly, so that the total pressure in the hearth of the furnace may easily approach 50 lbs. per square inch.

If this be not firmly resisted, if the least yielding takes place a crack will occur in the brickwork and the metal instantly following this crack will approach the outer wall of the structure which supplies its physical strength, and if it succeeds in reaching this at some point not completely protected, the stream of liquid iron will quickly cut a hole through the iron or steel jacket around the brickwork, and the stream of metal flowing through this hole will enlarge it with a rapidity which is almost beyond belief except by those unfortunates who have had experience with this action.

In one case which came under my personal experience the stream of iron cut through the hearth jacket a hole elliptical in shape and about 3 ft. long by 1 ft. high with its long axis horizontal. Even if the hole be many times smaller than this the liquid contents of the furnace are ejected through it in a few minutes, under the combined action of their own weight and the pressure of the blast, and this vast mass of molten material, with the tremendous cutting power which flowing streams of such material have, destroys in short order anything metallic in its path and in very many cases has cut and seriously damaged the columns supporting the furnace structure. If this runaway body of metal strikes a wet place on the floor of the cast house or on the ground an explosion is almost certain to result which may be disastrous in its consequences. Furnaces have even been put out of blast by the results of such breakouts, and even worse cases are only too numerous in which men around the furnace have been injured or killed by such accidents.

For this reason the construction of the hearth and bottom of the furnace has received an enormous amount of consideration and experienced furnacemen are quite generally of the opinion that any reasonable amount of money spent in securing a construction immune from breakouts is well invested, a conclusion with which I thoroughly agree.

A construction which in general meets this object has finally been developed, and is illustrated in Fig. 164, which shows in vertical half

section the lower part of the blast-furnaces of the Inland Steel Company at Indiana Harbor, Indiana.

The metal part of the construction consists of a series of steel staves with coils of cooling pipes cast in them, which extend from about $4\frac{1}{2}$ ft. above the bottom level of the furnace to about 6 ft. below it. These are not fastened to each other, but are surrounded by an outside jacket. The lower part of this consists of a heavy rolled-steel jacket riveted together with internal and external butt straps, no pains being spared to make the strongest joint possible. This jacket is separated from the staves by a small expansion space filled with yielding material.

The upper part of the staves is surrounded by a cast-steel jacket which also has water-cooling pipes cast in it. Its staves are fastened together by links shrunk on to the projecting lugs. They are of great thickness and, being made of steel castings, are enormously strong, but are further reinforced by rolled-steel bands about 3 in. thick by 1 ft. in height around the top and bottom. The edges of the segments of this upper cast-steel jacket are carefully planed to make a perfect joint, it having been found by experience that if there be an open joint in the jacket, no matter how solidly the brickwork may be built inside it sooner or later the iron is likely to worm its way through the brickwork and reach this crack. The instant the iron reaches it and begins to flow through it, the cutting power of the metal enlarges the crack and soon a full-fledged breakout takes place, which nothing can stop until the furnace is empty.

For this reason no pains or expense are spared to make hearth jackets not only strong enough to resist the expansion of the brickwork and to prevent their rupture by this action, but also to make them of practically air-tight construction.

It was formerly considered by many furnacemen exceedingly dangerous to have internal water cooling below what is known as the iron line — that is, the height to which the iron may rise in the ordinary course of operation — this height being normally some 2 or 3 ft. below the center of the tuyères, though in case of trouble the iron may rise up to the tuyères. The reason for this objection to water-cooling is that a current of iron flowing with considerable velocity will cut a water pipe or other cooling apparatus with the water flowing through it, since it is impossible for the water to remove the heat as fast as the stream of iron supplies it. When a cooling member is cut in this way explosions are almost certain to occur, and these are more disastrous the more confined the location in which they take place. Many frightful accidents have occurred through the cutting of water-cooled parts by molten iron.

When the joints in the outside jacket are absolutely tight such a flow of metal cannot start, and as it is only a flow which possesses this

tremendous cutting power, the cooling pipes are not endangered by this action when there are no crevices through which the iron can flow past them. By the combination, therefore, of the tight jacket and the water-cooling staves inside it, the danger of breakouts, which formerly was almost the worst dread of the furnaceman's life, have been reduced to a minimum, almost to a negligible quantity.

It will be noticed in Fig. 164 that there is a thickness of three feet of brick at the top of the hearth jacket, and that this increases toward the bottom. This is for the reason that the high velocity at which the blast is injected through the tuyères gives it a mushrooming effect indicated in Fig. 164, which throws it back against the wall around the tuyères and tends to cause severe cutting, augmented by the heat and chemical activity of the molten iron and slag. These jointly tend to cut away the hearth as shown in dotted lines, but by having an ample thickness of brick and having the line of water-cooling of a much larger diameter than that of the nose of the tuyères, the water-cooled surfaces have a better chance to overcome this combined action, so that furnaces built in this way cut back to a certain distance and then stop, whereas if the outside diameter of the hearth were made smaller in relation to the tuyère diameter the probabilities are that it would eventually give way under the joint attacks of these three influences.

It was formerly thought that every furnace had to have one or two breakouts when it started to working properly, soon after it was blown in. In the days when furnaces were small and the quantity of iron in them at one time was only a few tons, this, while a bad condition, was endurable, but, as furnaces and their outputs have grown and the amount of metal released by a breakout has increased, it has become increasingly necessary to solve this problem almost irrespective of the cost of the construction. The evolution of the general type described is the result of necessity, of much thought and of many unsuccessful designs.

The ditch around the hearth jacket. — There is ordinarily a ditch around the outside of the hearth jacket extending from just above the base of the columns, which are bricked in solid, up to about a foot above the hearth level, and practice in regard to this ditch has varied greatly. It is customary to use this to carry off the waste water from the tuyères, coolers, etc., and formerly these ditches were kept full of water to their tops, with the idea that this furnished effective cooling of the hearth jacket and tended to prevent breakouts. But in order to keep the ditch full of water its outlet must be dammed, and when this was done if a breakout did occur the molten iron filled up the ditch to the level of this dam, part way or even all the way around the furnace, and when cold had locked itself between the columns and the hearth jacket, whence it was almost impossible of removal.

At one time the practice prevailed of filling the ditch to the top with large lumps of limestone piled in as loosely as possible, then if a breakout occurred the decomposition of the limestone by the heat and the subsequent slacking of the lime tended to crack apart the mass of iron, which, of course, was much reduced in quantity and solidity by the presence of the lumps themselves. This practice is an improvement, but the practice of carrying the ditch full of water is itself going out of vogue to some extent, and personally I would never have the water in the ditch more than a couple of inches deep. This enables the ditch to be kept open to the bottom, and if a breakout occurs the molten iron will run out the outlet and leave the ditch comparatively free. Moreover, more effective cooling may be obtained by the spray from a small circle pipe causing a thin film of water to trickle down over the hearth jacket than can be obtained with a large body of standing water. This has often been established and is another illustration of the principle that rapid circulation has more to do with heat conduction than the amount of surface and conductivity of the material involved.

Allowing the outlet from the ditch to carry off the iron in case of a breakout has some disadvantages because the iron itself will run along the bottom of the ditch underneath the water for long distances, even in quite small quantities. I have known it to go 60 or 70 ft. and plug up the screen over the waste opening into the sewer so as to create a fearful nuisance.

To meet this situation two expedients are available, one of which is extremely simple and should always in my judgment be used. This consists in having an auxiliary outlet from the ditch normally kept closed and designed to discharge at some point sufficiently removed from the furnace so that any iron carried off by it may do as little harm as possible. This ditch may be closed either by a hand-operated gate or by a thin lead plate. The latter will cut off the flow of water effectively, but will melt in case iron strikes it and open up the emergency outlet. This should preferably be placed lower than the main outlet so as to drain the iron completely away from the latter. The use of this expedient once in my experience saved a shutdown of many hours.

The other expedient is somewhat more expensive. It consists in building a large chamber or cistern in the bottom of the outlet ditch, which is covered over by the cast-house floor plates under ordinary conditions, and stands full of water all the time, the waste-water current simply passing across its top, but if a breakout occurs the iron will run into this cistern and has to fill it up before it can go on through and make its way into the outlet sewer, the plugging of which constitutes a calamity of no mean order. If the cistern be made large

enough it cannot be filled up with the iron from any one breakout and is safe from being overflowed.

It is frequently customary to have the ditch around the furnace interrupted by a solid structure of brick on which the iron trough beneath the tapping hole is supported, but I do not like this construction, as the heat is drawn through the hearth jacket by the poulticing action of this brick pier and the circulation of water is cut off by it. Moreover, in case of a breakout the presence of this dam in the ditch prevents the iron from draining away in that direction and may result in permanently filling the ditch with a mass of iron on one side of the pier or the other.

By riveting a pocket a little larger than the outside of the iron trough air-tight on to the front of the hearth jacket the trough can be set down into this and a joint made between the two with cement, the water can then rise practically to the bottom of the iron trough without any danger of getting into it, and yet have an absolutely free circulation around the base of the hearth jacket at this point, which probably needs it more than any other.

In very recent years the security against breakouts has become so great that in some cases, the ditch is abolished and the hearth jacket is concreted in solid.

The tuyère zone. — This is the zone between the top of the hearth jacket and the bottom of the sloping bosh. Various styles of construction have been adopted for this, as for all the other regions of the furnace. One of these which had much vogue at one time was the use of a heavy cast-iron or even cast-steel tuyère jacket with cooling pipes cast in it, and with openings cast through it of the size required by the coolers, no internal cooling by cooling plates being used.

This construction and all others which depend on external cooling in this zone are in my opinion faulty for the reason that the tuyères must project a considerable distance into the furnace. If they did not, what I have called above the mushrooming effect would rapidly destroy all the parts adjacent to them; therefore, we have first the hollow-walled cooler as a sort of second line of defense which projects into the face of the brickwork. Then fitted into this and projecting about a foot beyond it we have the tuyère itself, which is literally on the firing line, its nose being some $3\frac{1}{2}$ or 4 ft. from the exterior of the brickwork.

The mushrooming effect of the blast, if this zone were without any but exterior cooling, would soon eat away two or three feet of the face of the brickwork, which would leave the heavy coolers carrying the tuyères without adequate support. This in turn would allow them to drop down so that instead of directing the blast in horizontally, as they should, it would be blown downwardly into the bath.

To overcome this and to protect the zone around and between the coolers from this intense mushrooming effect, cooling plates should be used as shown in Fig. 164 (page 240) and described below.

Cooling plates. — These are hollow plates of copper, or copper with one or two per cent. of tin to make it cast more readily, with a taper in the vertical plane, as shown, and also in the horizontal plane. These are supplied with water from the cooling-water system and a constant circulation is kept up through them the same as in the case of the tuyères.

They are built into the brickwork, but on account of the taper above mentioned can be withdrawn by means of lugs provided in their rear or outer surfaces for that purpose. These plates have great cooling surface and corresponding protective power for the brickwork around them. They increase the resistance of the brick to the action of the fire, and the brick to a great extent protects them from the direct attacks of the latter, although frequently they are directly exposed to it, as are the tuyères, but able to resist because of the activity of the water-cooling, in exactly the same way that the firebox of a locomotive is able to withstand the intense combustion of the coal within it because the thin plates which constitute its inner surface are so completely cooled by the water around them.

It will be seen that these cooling plates with their ability to withstand the direct action of the fire, protect the firebrick work underneath and around the coolers from the attacks of the iron, the slag, and the mushrooming effect of the blast, and so enable these to maintain their correct position throughout the campaign.

In order to supply the element of strength against the internal pressure of the furnace two constructions are possible. Either bands can be passed around the furnace just above and just below the cooler openings, leaving the space between these bands unprotected, or the bands may be connected by vertical buckstays which protect the intermediate space. The construction which I like best of all, however, is to make a solid jacket of steel plate, as shown in Fig. 164, with the flange at the base resting on the top of the hearth jacket, with holes cut through it at the points where the cooler openings and the cooling plates come. This supplies the means of holding all the brickwork to its place, which is necessary, for, in the absence of such protection, it is surprising how small a mass of unbound brickwork will detach itself from the rest and work out of the furnace under the action of expansion, pressure, etc.

The bosh. — This divergent cone which begins at the top of the tuyère zone has received attention at the hand of a vast army of engineers and furnacemen, and many solutions of the problem of a suitable construction have been attempted. The divergent shape of this

portion of the structure and its relative lack of solid foundation upon which to build a patch if it fails, combined with the scouring action of the blast traveling up it, and of the semi-reduced iron and scouring slag traveling down it, have made the problem of maintenance of this part of the furnace a difficult one.

One of the most commonly used constructions is that shown by the upper portion of Fig. 164. It consists of several rows, in this case eight, of cooling plates, those in one horizontal row alternating in vertical location with those in the rows above and below it. In other words, the plates in each of the eight horizontal rows are not vertically above one another, but are staggered for reasons of mechanical strength, because the plates are very much weaker against compression stresses than the brickwork, and if they were all in one row might be crushed by the expansion of the bosh walls due to the heat. By having them in alternating rows larger masses of brickwork intervene between them, making a sort of series of arches which do not readily crush. Moreover, if all these cooling plates were arranged in vertical rows, the brickwork between these being relatively without protection would be scoured out by the erosive actions I have mentioned.

By staggering the plates vertically the space between a pair in one row is protected to a great extent by the plates in the other rows above and below that space. This construction is shown in Fig. 165 (page 248). Just above the bustle pipe portions of two rows of cooling plates and their vertical staggering may be quite clearly seen.

The cooling plates must be protected from the weight of the brickwork above them and this is done by one of two methods. Either a flat arch is turned in the brickwork above them or a cast-iron box is built into the brickwork which projects in from the outside of the wall about one-half or two-thirds the length of the cooling plate, which is inserted through and protected by this box. Both methods are good but the brick arch is much cheaper and just as good for all practical purposes, so is to be preferred. Circumferential strength is supplied by very heavy bands of steel running around the bosh between the rows of plates.

This makes a good, strong, substantial construction, but in addition to being very expensive on account of the great quantity of copper castings required, it is liable to one serious fault. This is that the erosional influences I have mentioned cut out the brickwork between the plates and leave the noses of the latter sticking out into the furnace almost like a flight of steps. I have tried to illustrate this action by the dotted lines in Fig. 164 and can state most emphatically that the conditions shown by this sketch represent only a fraction of the erosion that I have seen in actual practice after a campaign of only a year or two.

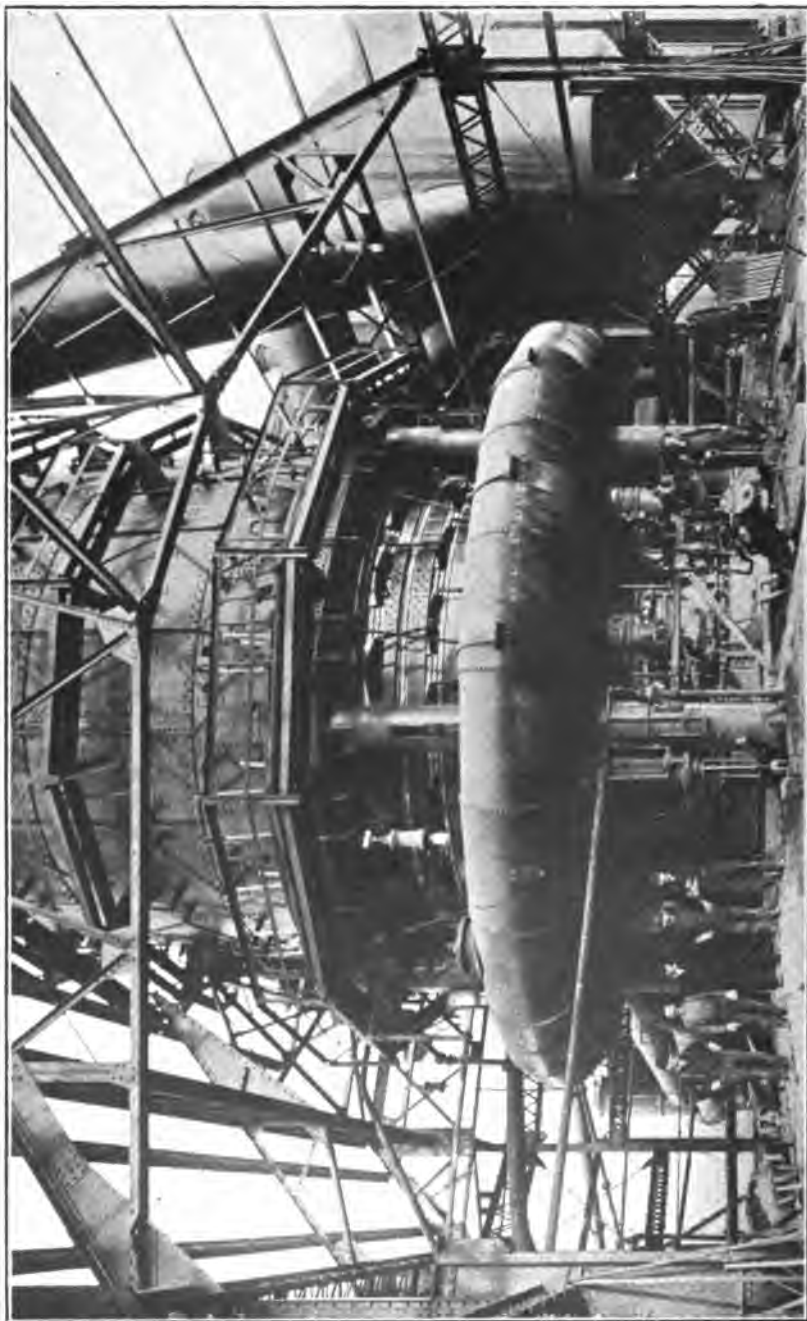


Fig. 165. Lower portion of furnace shown in Fig. 1.

When the action has proceeded to the extent indicated or further, the shelves formed by the projecting noses of the cooling plates make ideal lodging places for half-molten slag and such materials as it cements together, and such a mass builds up on the noses of the plates at times with considerable rapidity. Then a change in the condition of the furnace comes about or the accumulations are no longer able to maintain themselves on the narrow footing offered by the cooling plates, but in either event the whole mass sloughs off into the hearth and having no time to be treated by the heating and reducing action of the ascending gas is precipitated into the hearth in a half-raw condition with resulting ruin to the iron and slag already formed therein, and the partial chilling of the furnace, perhaps to a serious extent.



Fig. 166. Segmental bosh jacket built by Birdsboro Foundry & Machine Company.

It is these steps and the consequent irregularity of the work of the furnace at times which has led some furnacemen to abandon this type of construction for one whose wearing surface should be smoother and more regular. This result has been sought in some cases by building up a water-cooled bosh jacket of cast-iron segments as shown in Fig. 166. These segments as shown are strongly bolted together to supply the necessary strength to resist the pressure, and then receive a thin lining of brick, its thickness depending upon the opinion of the furnacemen as to what is necessary, but commonly from nine to eighteen inches. This is an expensive construction and requires careful machining throughout, because if the least crack exists the gas will blow out through it with destructive effect and on account of the

crack being small it is almost impossible to get anything in the nature of a clay stop to stay in it.

A third type of construction consists of a bosh jacket made entirely of steel plates and cooled solely by external sprays. This can be made an absolutely air-tight job of boiler work, thus eliminating any possibility of gas leakage such as I have described, while the cooling by means of a continual film of water on its exterior surface produced by sprays is one of the most efficient forms which can be obtained in any way whatever, a much greater surface being exposed to the cooling action of the water than in the case of the cast-iron built-up jacket.

One feature of a jacket of this kind must receive the most careful attention. It must be as near absolutely smooth as it can be made by good workmanship. The rivets must be countersunk on the outside and driven down absolutely flush so that a film of water will travel over their heads without any interruption, and in general everything must be done to remove even the slightest obstruction from the path of the water film, because this film travels down the surface with considerable velocity and even a minor obstruction will throw it off, leaving a dry spot below the obstruction. This dry spot becomes hotter than the rest of the jacket and causes contraction strains and in time cracks result, while if it be a large one the lining on the inside of the jacket will melt off and the jacket itself will then be exposed to the assault of the streams of iron and slag running down inside it, which will soon cut a hole through it. Such holes are almost impossible to stop without a long shutdown on the furnace to enable a patch to be put on, and as this can only be done with patch bolts it is never nearly so good as the original jacket.

This is one of the places where an ounce of prevention is worth a ton of cure, and the only proper course is to make it impossible for a dry spot to form on one of these jackets.

Fig. 167 shows a furnace reconstructed according to the plans of the writer with a jacket of this type in which absolute smoothness was obtained by welding it up with an oxy-acetylene burner, then chiseling off the roughness at the joints and grinding it down smooth, an operation which took little time and cost a relatively small amount, something like a couple of hundred dollars above the cost of boiler work.

This jacket was flanged out at top and bottom to avoid the necessity of riveting angles on it to make connections to the mantel plate above and to the trough at its base. By flanging the metal out bodily these riveted joints are avoided.

Water is sprayed onto the top of this jacket by a circular spray pipe divided into eight sections, each of these being connected to the

water supply separately, and each of them also being in duplicate, only one being used at a time. If one becomes obstructed or fails the other can instantly be put on. This feature, as a matter of fact, is used only when it is occasionally necessary to clean out one of the sections, but it is a convenience at that time and contributes to safety at all times and is well worth the trifling expense.

Some care should be taken to supply the water to these sprays under a very moderate head and make the holes in the spray pipes fairly large. They are then much less likely to become obstructed by small threads of pump packing and like and can be made to deliver the water exactly at the top line of the jacket with a minimum of spattering, the water thrown on to the jacket flows down it in a smooth film and the spatter is caught by the annular funnel shown about half way down the jacket, which is not riveted to the latter but comes in contact with it through a serrated edge at the bottom of the funnel. This serrated edge gives sufficient flow at every point around the circumference, which would not be the case if the bottom edge of the funnel were straight as the contact would be close enough in that case to cut off all flow in places.

By having the funnel hung from above by independent hangers it is possible to adjust with small wedges the location of its bottom edge in relation to the jacket to regulate the flow and get it uniform around the furnace, which could not so readily be done if the two were rigidly connected. Moreover when the funnel is supported from the jacket this involves rivets in the jacket for the funnel brackets and below these rivets it is almost impossible to avoid having a dry spot as above described.

This jacket was so extremely smooth and worked so admirably in service that the intermediate funnel could probably have been dispensed with entirely by widening out the bottom trough a little more and perhaps putting some flanged extensions around its upper edge to catch spatter.

The trough as shown projects out beyond the base of the funnel, but should have been made three or four inches wider than it is, because some of the drops from the bottom edge of the funnel are deflected from the vertical line by capillary attraction and fall outside the line of the trough which causes disagreeable spattering down below.

When using a construction of this type it is not only possible but far preferable to use a very thin brick lining in it, because the brick being cooled only from the outside, no matter how thick originally will rapidly wear down to that thickness at which as much heat is carried away from their bases as the currents of molten material and gas supply to their front surfaces. This is only a few inches and if three feet of brick were to be built inside such a bosh jacket in the course of a few months it would all be gone down to a few inches, ex-

actly the same as if it had started at one foot or even nine inches in thickness. Consequently if the furnace were the correct shape to begin with it obviously could not be so with three feet of brick scoured off the bosh all around, therefore the thing to do is to put in only as much brick in the first place as the furnace may be expected to leave there after it has settled down to regular work.

In coke furnaces using a bosh of this type I have several times used only nine inches of brick with very satisfactory results, and in the furnace shown by Fig. 167 which was to use charcoal and therefore much easier on the lining than a coke furnace, I used only four and one-half-inch bricks made up specially as circle bricks to fit the curvature of the bosh. This furnace was blown out on account of commercial conditions after a campaign of about a year and a half, and two inches of the original brick was still left. The judgment of the furnace-men was that it was as good as new.

A point about this construction which must not be overlooked is that the lining in this portion of the furnace is practically self-renewing. If the brick were all scoured off the jacket clean, by bad slag or bad work of the furnace, and the water-cooling were maintained, within a few hours the furnace would have built back for itself a lining of slag, carbon dust, etc., just as resistant for its purposes, if not more so, than the firebrick initially used.

This condition arises from the fact that this portion of the furnace converges toward the bottom, and that any material chilled on it tends to stay because of its conical shape. This is a feature of much importance which does not exist in any other portion of the furnace.

Owing to the small quantity of brick in the lining of the bosh in this construction it is without much compressive strength and differs in that respect from the cooling plate construction of Fig. 164 in which a considerable portion of the weight of the furnace structure is carried on the hearth and bosh walls when the latter are heated up by expansion. With the steel-plate bosh construction this must not be allowed to happen, as the thin brick lining would quickly crush and the steel jacket buckle under compressive stress, with disastrous consequences. It is necessary, therefore, to provide a sort of expansion joint in which the expansion due to the heating of the brick can be taken up without objectionable consequences. That is accomplished in the present construction by making the lower portion of the bosh jacket proper, cylindrical, and putting inside it a set of cast-iron water-cooled housings or blocks, B, through low openings in which project cooling-plates as shown at A. These cast-iron housings and the cooling-plates are supported on the heavy brick structure around the tuyères which extends up from the bottom. The bosh jacket and its lining on the other hand are practically suspended from the mantle.

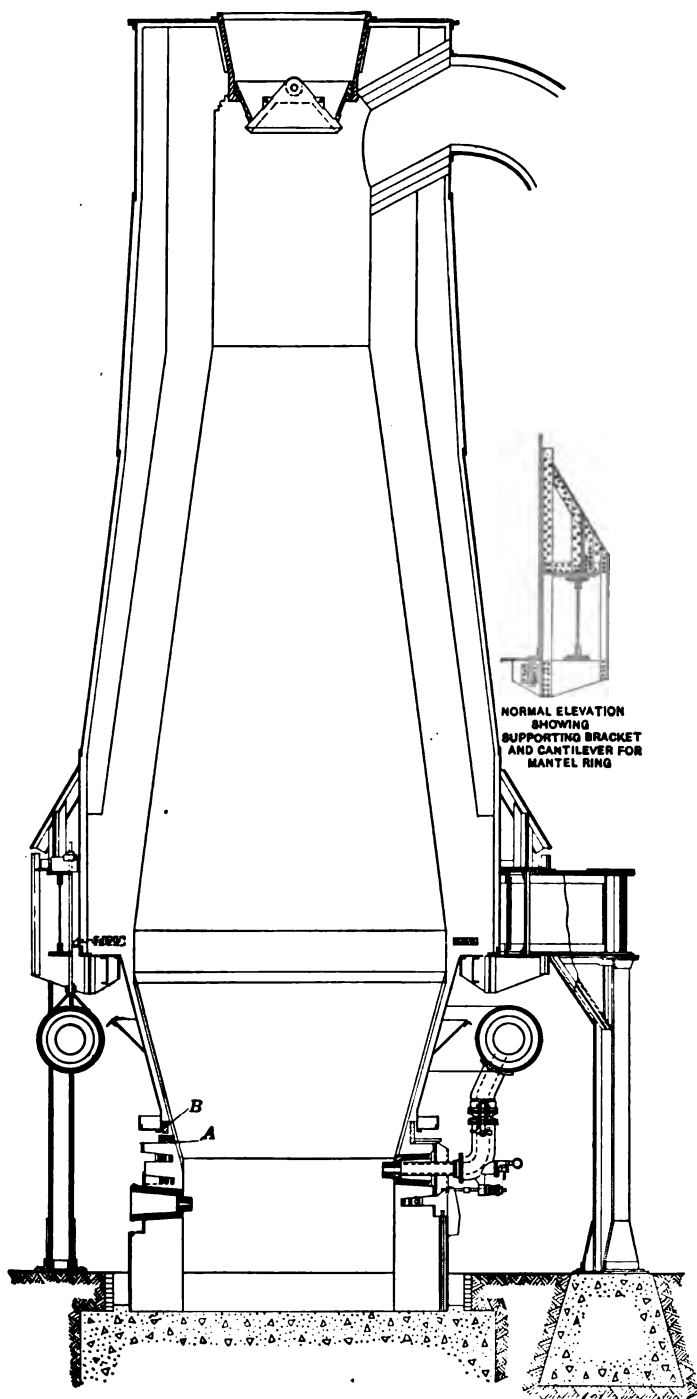


Fig. 167. Charcoal furnace, showing steel bosh jacket construction.

When expansion takes place the cylindrical portion of the bosh jacket slides down over the water-cooled housings, and if the lining is cracked or broken by this action, the crack is at once sealed by cinder running down over the surface and chilling against the housing and the bosh jacket.

In order to avoid the necessity of lugs and fastenings on the housings they are held together by the band, B, around their tops, this band being protected from burning by the cold bosh jacket just outside it and the water-cooling within the housing.

The water pipes for the cooling blocks A were brought out at the bottom so that the maximum of expansion could take place without shearing off these pipes, which has been known to happen in a construction of this kind where this provision was not made for it. Even in this case it would have been better if the space between the bottom of the trough and the top of the solid brick wall had been made three or four inches higher.

The water-cooled housing and the cooling plates projecting through them perform a double function: first, they protect the tuyères and coolers below them from the scouring action of the streams of iron and cinder and prevent the spaces between the coolers from being scoured out and so weakening the tuyère zone; secondly, they form a water-cooled shelf at the foot of the bosh slope which supports the lining of the latter and forms a ledge on which a new lining can start to form in case the old one is scoured off by irregular furnace work.

Both these functions are of great importance and some element of construction must be supplied to perform them if this type of bosh is to give the long and useful service of which it is capable. When properly designed there is no doubt that this type of bosh construction will give absolutely satisfactory results in furnace operation on account of the perfectly smooth slope of its working surface and the complete absence of steps on shelves, at a cost of construction which is literally only a small fraction of that of the cooling plate or water-cooled stave construction.

The shaft or inwall.— Above the mantle only two styles of construction have been used in recent years. For many years nothing but plain firebrick from two to five feet in thickness was used from this point to the top of the furnace, but the tendency for the lining to be eaten away more extensively just above the top of the bosh than anywhere else, which had existed very generally for many years, became worse with the general use of fine ores, and the lining troubles which they brought with them.

As the cooling plate construction had given a good account of itself in the bosh, furnacemen began to put rows of cooling plates

above the mantles to prevent this action, and this practice is now quite frequently followed. These were at first simply built in the brickwork and the pipes to them were brought in through small holes cut in the shell for that purpose. This, of course, put these cooling plates entirely beyond the possibility of renewal; if they failed they were done with and must be shut off and were soon burnt up.

To meet this situation some furnacemen have cut holes through the furnace shell large enough to permit the removal of the whole cooling plate exactly as is done on the bosh, but this cuts up the shell very badly and even when this provision is made it is a matter of much difficulty to remove these plates through such a great thickness of brickwork. It is, therefore, doubtful whether the trouble and expense of making these plates removable is worth the small gain to be obtained by that means. It will be seen that in the case of the furnace shown by Fig. 165 the course was adopted of bringing the water pipes for these blocks out through the shell so as to give access to the several connections, but without making any provision for the removal of the cooling plates.

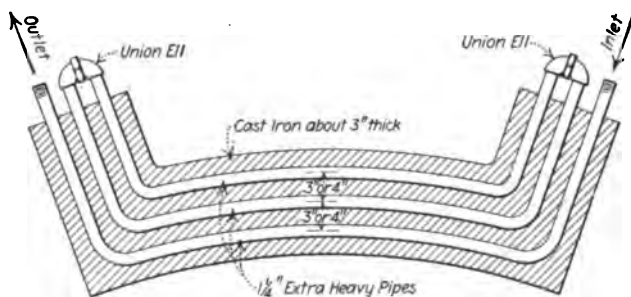


Fig. 168. Cast-iron cooling plate.

In early days of cooling plates they were made of cast iron with coils of pipe cast in them, these in all cases being built solid in the brickwork, without any provision for removal. The pipes were first made in one continuous coil zigzagging back and forth through the cooling plate, but an improvement on this was subsequently introduced which consists in making each pass of the pipe through the block separate and bringing the ends of all the pipes out through the outside surface of the plate, and putting the connections which put them in series on these projecting ends. By this means if the inside pipe failed it could be cut out and the one back of it left in service; if this failed by the gradual burning back of the furnace, it could be cut out and so on back for as many passes as the pipe might make through the plate, this in turn number generally being from three to five. This arrangement is shown in Fig. 168.

For the protection of the bosh, cooling plates made of bronze, described above, were a great improvement. Bronze has a great advantage over iron, in that iron and cinder do not adhere to it, so that the cooling plates stay perfectly clean and as a result of this and of their shape they can be pulled out of the furnace without much difficulty and replaced whenever they fail so that the inside of the furnace is kept practically to the original lines for a long period of time.

On account of this superiority for service below the mantle, the bronze cooling plate has often been used above the mantle also, but after considerable experience with it I prefer for that service the cast-iron plate with pipes cast in, for two reasons.

First, these plates above the mantle being the highest of any of the water-cooled portions of the furnace they are the first to lose the water in case of any partial failure of the water supply which reduces its head. I have known of several cases where this happened without the complete failure of the water supply. This means that these cooling plates above the mantle are the most likely to lose their water, and if they do so the bronze plates are bad for two reasons. First, the melting point of the bronze is many hundred degrees below that of the cast-iron plate and its mass is much smaller, the body of the plate being hollow, so that when the water on these plates has been lost, even though the furnace be stopped at once, the heat of the surrounding materials causes the bronze to melt after a comparatively short period, this leaves a considerable cavity in the brickwork into which the bricks from above are likely to settle, thus causing at least the possibility of a crack in the lining, even if the gas does not blow out through the burnt cooling plate itself, as it often does.

With the cast-iron plate, on the other hand, the conditions are quite different. The melting point of cast iron is not reached by the contents of the furnace at a point much above the mantle, so that these plates are much less likely to be melted out completely than the bronze plates, and even if the inner end next the stock is melted off the outer end is protected by the brickwork for a long time, if not indefinitely, and being practically solid except for the pipes cast through it, a partial melting of the cooling plate does not form a cavity as in the case of the bronze plate.

Secondly, if even a small portion of the nose of the bronze plate be melted off it is destroyed completely, as this opens its water space into the furnace, but with the multiple-pipe system several inches of the plate may be melted away and still, by using some of the rear pipe passes, water may be put through it again, and its usefulness as a cooling member preserved indefinitely.

When these plates are installed, whatever kind may be used, provision must be made for obtaining access to them. In Fig. 165 two

platforms for this purpose will be seen above the platform at the level of the mantle, these platforms being provided with a suitable hand-rail. This is important because in case of trouble with the circulation in these plates it is necessary to obtain access to them quickly in order to prevent their being burnt, and this cannot be done if ladders have to be arranged for the purpose. Moreover there is always a certain quantity of furnace gas stealing up the walls of the furnace, no matter how well it may be constructed, and while this may be so dilute that the workman exposed to it will not realize the danger, he may nevertheless be made unconscious by it. Under such conditions if working from a ladder he is almost certain to fall and be seriously injured or killed, whereas if a secure platform with a good hand-rail be provided he will fall upon this and can easily be rescued before further poisoning by the gas.

The number of rows of cooling plates above the mantle is a matter of the individual conditions and the judgment of the operator. The customary number is probably from three to six rows, although in several cases these rows have been run all the way to the top of the furnace, spaced about as shown in Fig. 165. This is often done with furnaces intended to be run on ferromanagnese or spiegel which are highly destructive of their linings. For ordinary furnace practice the consensus of opinion is that there is no advantage in having more than a limited number of rows of these plates.

There is a drawback to the use of these plates in that while they prevent the lines of the furnace from cutting back at the plate they do not prevent heavy erosion in the space between the adjacent rows very much as shown for the bosh in dotted lines in Fig. 164 and the steps so formed offer a lodgment for scaffolds in the very region of the furnace where the stock is in its pastiest condition and therefore most likely to scaffold. Consequently these steps tend to promote scaffolds with all their disastrous consequences.

For this reason some operators prefer not to use cooling plates above the mantle at all, but to let the lining wear away and cool the shell externally with sprays if it becomes necessary. It is stated by Mr. H. A. Bassert in his paper on Modern American Blast Furnace Practice read before the American Iron and Steel Institute, May, 1914, that "cooling plates above the mantles have only survived where they are placed from 18 inches to 22 inches back of the face of the inwall and in this position they have not much effect in preserving the original lines."

This statement may not be universally true, but may be considered as absolute proof that cooling plates above the mantle are not a panacea for lining troubles but on the other hand are only to be used sparingly and with great discretion.

From this region at the base of the shaft to a point a few feet below the stock line conditions of the temperatures and abrasion are such that well-made firebrick alone will withstand a long campaign, and consequently in much modern practice nothing else is used.

The stock line and the top of the furnace. — In this region the influences of chemical activity and temperature are greatly reduced over what they are in the lower portions of the furnace, but the lining is exposed to another form of attack which has proven almost as difficult to resist as that in the hearth and bosh.

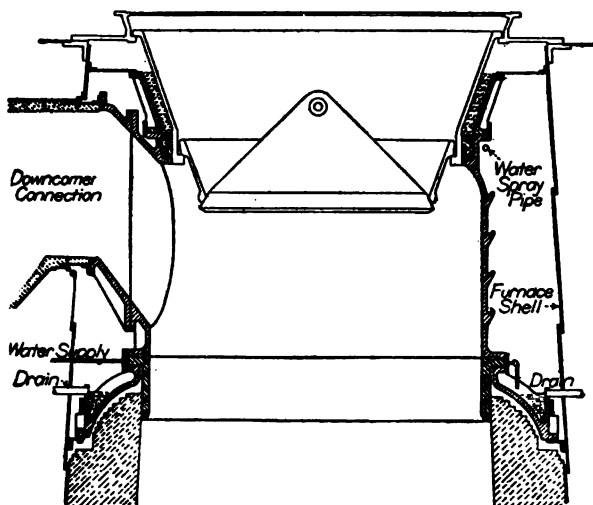


Fig. 169. Broden-Roberts stock line protection.

This is the abrasive action of the stock as it is dumped from the conical bell into the furnace. The charge of coke in a modern furnace is from six to twelve thousand pounds, and in the best modern practice this is an extremely hard dense coke. In practically all cases also the limestone is in the form of lumps; sometimes this is crushed to go through a three or four-inch ring, but in many cases lumps which would scarcely pass through an eight-inch ring are tolerated, such lumps weighing up to twenty pounds or more.

When the bell opens these slide off its steeply inclined surface and strike violently against the lining at the stock line. In some cases also a considerable portion of the ore consists of hard lumps, some forms of ore having not only a high specific gravity, but also a degree of hardness comparable to that of granite, though these conditions are not usual in most present practice. These materials with their hard and abrasive nature impinging on the stock line at a rate varying from one to two thousand tons per day cannot fail to exercise a destructive effect upon any brickwork used for the lining, and as a conse-

quence many forms of metallic protection have been used for this portion of the furnace.

The earliest form of protection known to me was angles of cast iron, six inches square on the face, six by nine inches in the body, by one inch thick. These were laid in fireclay on top of a course of brickwork, and another course of brickwork six inches thick built on top of them, then another row of angles was inserted, and so on. This armor extended for some eight or nine feet vertically in the furnace from a point two or three feet above the stock line to one seven or eight feet below it.

These after many years' trial proved to be unsatisfactory. The ends of the plates would break off and the protection of that area would be lost, but more serious still, cast iron swells when repeatedly heated and cooled through certain temperature ranges, and these are ranges which exist at the top of many furnaces.

It is probable, moreover, that a graphitization of the carbon in these plates occurs in consequence of their long heating, and this also is accompanied by swelling which tends to disintegrate the structure of the angle. Moreover, this swelling took place unequally at different points around the circumference of the furnace and the top of the brickwork was not only pushed up to an objectionable extent by the action but also at some points more than at others.

At other times and plants steel mantles or circular shields slightly smaller than the brickwork were hung inside the furnace at the stock line, but these failed because while the temperature at that point is not normally high enough to affect the structure of wrought iron or steel, it is high enough to cause those materials to warp very extensively in course of time, and if these mantles warped at all they must go inward since the brickwork close outside them prevented them from warping outwards. Such irregular projections of portions of the mantle into the furnace utterly destroyed the regularity of the stock line upon which the proper filling of the furnace depends, and brought about the very conditions which the mantle was introduced to avoid.

Cast-iron or steel rings built up of segments were tried at some plants. These were built into brickwork practically like a course of iron or steel bricks at intervals of two or three feet vertically, but as the stock has a considerable outward velocity as it leaves the bell these did not prevent it from cutting into the brickwork between them, and they, therefore, failed to fulfil the purpose for which they were intended.

I have never used these myself and I do not know of any case where they have been continuously used by any one plant for a long series of years.

One of the earliest successful means of solving this troublesome

problem was an adaptation of the old cast-iron angles, first made so far as known to me, in 1903 or 1904, at the plant of the Longdale Iron Company.

After realizing the uselessness of the cast-iron angles, the suspended mantles, and various other schemes, it seemed likely that wrought iron being much lower in carbon than the cast iron, would be free from the tendency to grow by repeated heating and cooling, and would have also the physical strength needed to prevent breaking off the exposed portions of the plates in service. It would also be free from the liability to extensive warpage which had destroyed the steel shields because the individual angles, six inches square on the face, would have between them spaces of an eighth of an inch or so at the closest, and these spaces providing room for individual expansion would prevent objectionable warpage which was the result of the cumulative expansion of a considerable area of the mantle as a whole.

Accordingly a trial of such angles was made. These were made of three-quarter inch by six-inch wrought iron, six inches square on the face, six inches by nine on the portion built into the brickwork, and were successful far beyond our highest expectations. Instead of being compelled to reline the top of the furnace at the end of every campaign, as had previously been the case, a furnace would make two or three campaigns without disturbing the upper portion of the lining.

Since that time these angles have been used with some modifications at a considerable number of plants, and always, to the best of my knowledge, with entire satisfaction and success. Modifications have been made in some cases. The portion of the angles built into the brickwork has sometimes been made long enough to go entirely through the brickwork, and the outer end turned up into a hook, this being imbedded in concrete poured around the lining at the top of the furnace. I have never seen any tendency for these angles to work out of the brickwork which would necessitate this additional expense.

There is, however, a very simple method of preventing this, if such danger were anticipated, by a simpler and less expensive means. The leg of the angles built into the brickwork can be sheared to approximately the taper which will make them lie to the circle of the furnace, and the portion of the angle built into the brickwork, having its largest end out, would be absolutely prevented from working forward into the furnace. If the sides of the plates before bending were sheared to an unbroken straight line this would result in slight gaps between the turned-down portions or faces of the angles, but this would be a matter of no importance.

It is something of a nuisance to level up the outside courses of the brickwork so as to bring them level with the tops of these angles, when the latter do not run clear through the wall, and to avoid this

difficulty bricks of different thickness may be used on the inner row where the angles are laid. By using what firebrick makers call the standard thickness of brick ($2\frac{1}{2}$ in.) in the courses on which the angles are to come, and the three-inch thickness in the rear courses behind them, the thickness of a $\frac{5}{8}$ -inch angle is almost compensated with a minimum of difficulty in leveling up and without using any but standard material.

There are no patents on the use of these angles made of wrought iron or mild steel, though a patent on their use when made of hard steel is held by Mr. E. B. Cook.

Another type of metal protection for the top of the furnace is one designed by Messrs. Albert Broden, manager of the Reading Iron Company, and Frank C. Roberts of Philadelphia. This is shown by Fig. 169 and consists of a cast-steel sleeve the shape and size of the furnace itself at the stock line, which rests on cast-steel brackets securely riveted to the shell.

The downcomer opening is cast through this sleeve and all brickwork is left out between it and the shell of the furnace proper. Large openings are cut through the shell to render the sleeve accessible for expansion and to provide air-cooling for it. Water troughs are cast in its outer surface and provision made for a spray pipe around the top so that a continual trickle of water may be kept up over its surface in case of necessity.

The bottom section is cast separately and is cooled by water pipes cast in. This projects down inside the top of the brickwork and protects the upper edge of the latter from the abrasion of the stock. The cooling water is trapped from the pockets in the back of the brackets, which are fastened water-tight to the shell and so prevent any possibility of water getting down through the brickwork. The joint with the hopper at the top is made by a single layer of brick laid in the usual way. This is an excellent construction and has given good results since it was put into service a short time ago. The only objection to it is the expense; being made of steel castings with accurately machined joints at all points where the different portions come together, it is a very expensive arrangement.

The shape of the top of the furnace. — It was formerly customary to run the shell practically vertical to the top, putting brackets in the inside to support the hopper ring and other brackets on the outside to carry the wheelway for the filling barrows.

In early days the hopper ring was not even bolted down to the brackets, but with the greater frequency of violent slips which followed immediately upon the introduction of large percentages of fine ore into the burden, it was soon found necessary to have a more substantial construction. This was begun by making the brackets of steel instead

of cast iron and bolting the hopper and hopper ring to them. Finally Mr. Julian Kennedy pointed out the general weakness of this construction and the necessity of holding the top of the furnace down until the violence of the slip had passed by. In fact he claimed that by preventing the sudden release of pressure at the top the violence of the slips could be much diminished, and he was the first to introduce the coned top shown in Fig. 163 in which the shell is drawn in to support the hopper ring directly, thus making a much better and tighter joint between the hopper and the shell and giving a construction of sufficient strength to resist all ordinary slips and explosions.

The great mass of brickwork formerly put in above the bottom of the hopper is in fact perfectly worthless as it has no heat-resisting functions to perform and only serves to make a joint between the hopper and the furnace shell, and generally a very poor joint it was, having to be supplemented by clay packing, and accompanied by more or less leakage of gas, particularly during the blowing-in periods of the furnace when the gas is most deadly. The elimination of this construction has also resulted in putting the gas outlets further up toward the top of the furnace where they belong, somewhat as shown in Fig. 170, which is an elevation of the furnace shown in Fig. 163 and shows the location of the gas outlets more clearly.

The wheelway of the hand-filled furnace is of course entirely eliminated as such, in modern mechanically-filled furnaces, but an operating platform is provided, generally about as shown in Fig. 163.

Thin-lined furnaces. — It has been recognized for many years that firebrick exposed to the conditions in the blast furnace would wear back until the amount of heat carried off by their bases about equaled the amount brought in by their inside surface, after which wear took place much more slowly. It has also been recognized that in the standard construction satisfactory life of lining can only be secured by a corresponding thickness, and that as this thickness wore away the departure of the furnace from its original and presumably correct lines became greater and greater, generally with more and more unsatisfactory working.

About fifteen years ago with the idea of overcoming these difficulties the experiment was tried in Germany of making the lining of the furnace exceedingly thin, only a few inches in fact, and cooling its exterior surface so as to maintain its original shape indefinitely. The idea has superficially much to recommend it, and after several years' trial in Germany it was introduced into this country, first at the Lucy Furnaces in Pittsburg, under the management of Mr. James Scott.

The German construction consisted of cast-iron staves with flanges on their exterior surface and jaws like flanges on the inside, into which the bricks were securely fastened. These were built up into a furnace

shaft very much in the same way that the bosh jacket shown in Fig. 166 is built up, but the exterior was cooled by a water film or spray instead of the pipes cast in shown in Fig. 166.

The construction adopted at the Lucy Furnaces was different. There a steel shell was built much smaller in size in proportion to the lines of the furnace than the ordinary shell, since the thickness of the brick with which it was lined was only about one foot, from top to bottom. On the outside of this shell were riveted annular troughs, each about two feet deep by six or eight inches radial width, and arranged so that water pumped into the top one flowed down through all the others in sequence to the bottom. In spite of great pains to secure absolutely air-tight construction, some water leaked into the furnace through the rivet holes and the results were unsatisfactory, though subsequently these difficulties were overcome.

Soon after this two thin-lined furnaces of this type were built at the Illinois Steel Works, and subsequently one of these was rebuilt with cast-steel plates instead of the boiler-plate shell and riveted buckets. This, however, did not prove satisfactory and the latter construction was restored. A bucket type of thin-lined furnace was also constructed at the plant of the American Steel & Wire Company in Cleveland.

A thin-lined furnace was subsequently built by the Detroit Iron & Steel Company according to the plans of their general manager, Mr. Max McMurray. This solved the problem of saving the original shell for supporting the top works of the furnace, which had not been done in any of the other constructions, columns having been run all the way up from the mantle to the top for this purpose.

In the case of the Detroit furnace the expedient was adopted of building a smaller shell with a thin lining inside the original shell and cutting a number of doors through to give access to the inner shell for examination, this shell is cooled directly by water sprays at the top, these form a film of water which runs all the way to the bottom. The outside shell also presents the advantage of preventing the wind from blowing the water off the stack, thus leaving it dry on one side, and making a disagreeable spatter below, both very important points. This construction is shown by Fig. 171 (page 264).

The Tennessee Coal & Iron Company has also had a thin-lined furnace in operation for a number of years. This has a very heavy boiler-plate shell with spray pipes arranged around the top. A series of galleries are arranged at different levels around this shell and outside these galleries is a sort of housing of steel slats to prevent spatter and to prevent the wind from blowing the water off the shell.

A different construction still has been used by Mr. Frank C. Roberts in a furnace built by him for the Warwick Iron Company, shown in

vertical section in Fig. 172. In this the top of the furnace is supported by separate columns running up from the mantle, as previously de-

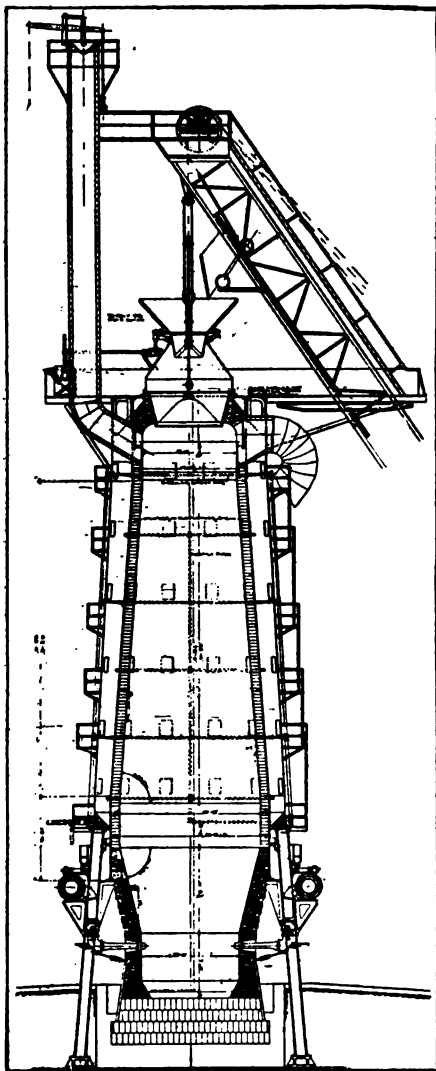


Fig. 171. Detroit Iron & Steel Company's thin-lined furnace.

scribed, and the shell is a boiler-plate shell, but instead of trusting somewhat to chance in the matter of the distribution of the cooling water around it, this is accomplished by a helical trough shown in larger section in Fig. 173 (page 266).

The trough is supported by tap bolts which do not go all the way through the shell and therefore make leakage through it impossible. The bottom edge of the trough is spaced away from the shell by distance blocks as shown. Part of the water runs out the space at the bottom of the trough and that which cannot get out this way runs around the helical trough. In this way a perfect distribution of water is secured around the circumference of the shell and the danger of wind blowing the shell dry on one side is eliminated.

A compromise, one-half thin-lined and one-half standard construction, has been in use for several years at the Port Henry Furnace of the Northern Iron Company. This construction shown in Fig. 174 (page 267) is that of the former manager of the company, Mr. F. E. Backman, the design being carried out by Frank C. Roberts & Co. This furnace has a circular mantle

shown in section, resting on the vertical portion of the columns at the level of the top of the bustle pipe. From this other columns run up on a slight inward batter to a second mantle some twenty-five feet higher. On this second mantle rests the upper portion of the inwall which is of standard construction. From this point down to the bosh

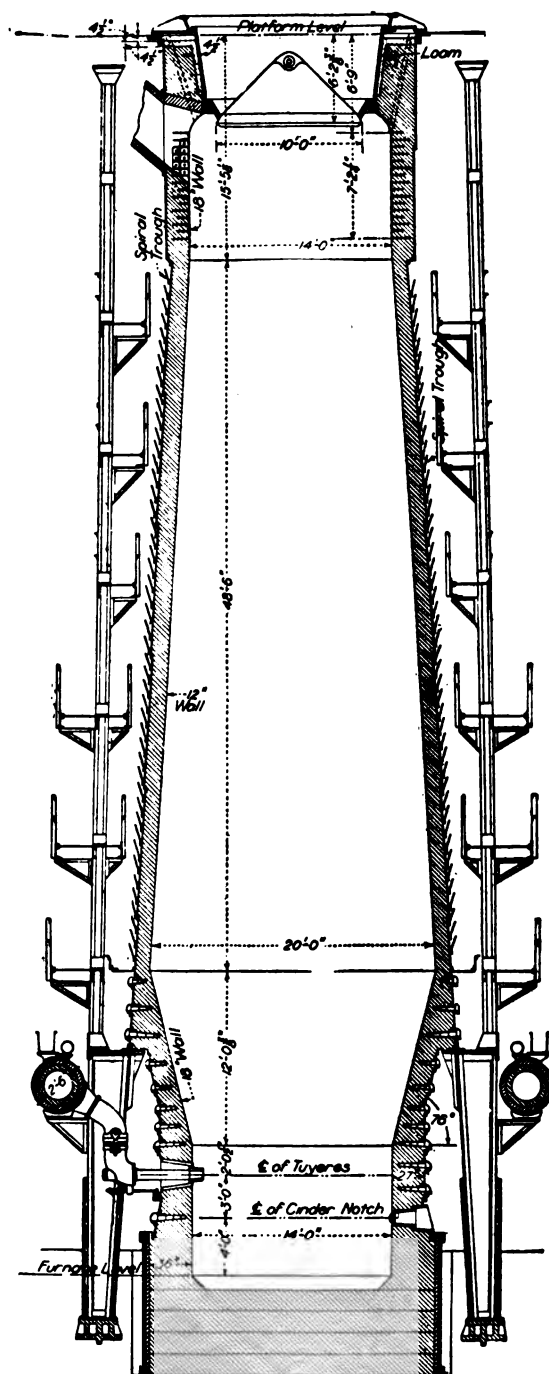


Fig. 172. Section of Warwick thin-lined furnace.

there is a boiler-plate shell with rings of angles for supporting the brickwork, riveted to its inside surface at intervals of five or six feet. This shell makes a joint on top of the cast-iron water-cooled segmental bosh jacket. The bosh jacket is lined with nine inches of brick and the nearly vertical portion of the shaft above it with thirteen inches.

This construction is intended to prevent the gouging out of the



Fig. 173. Spiral trough on Warwick thin-lined furnace.

lining above the top of the bosh which has been described above. This furnace has now been in operation for several years and is said to have given good satisfaction.

The conditions in regard to thin lining for the inwall or any point above the top of the bosh are vastly different from what they are below that point, because, as already pointed out, the convergent slope of the bosh provides a natural lodgment for the slag which runs down and chills upon its cooled surface in the normal operation of the furnace, so much so, that as before stated, if a furnace were started with an externally cooled bosh jacket entirely bare of bricks this would soon cover itself with a lining as good or better than the best firebrick which could be put upon it. But above the mantle the slope is in the other direction, the shaft of the furnace is a cone divergent downward, moreover except in its extreme lower portion there is no molten material, and if there were any it could not impinge upon this outward flaring surface, and could not remain there if it did so. Therefore if the lining is once removed from this portion of the furnace it is gone for good and all, until restored by relining.

Moreover the furnace shell does not furnish much support in the vertical direction for any lining which may stand against it. It does prevent this lining from pushing out or falling backward, but it does not prevent its falling inward or sliding straight down in case of the failure of its support below. For this reason it seems to me necessary that the lining of the furnace above the bosh should consist of a sufficient thickness of brickwork to support itself and the portion of the lining above it. Systems of angle supports riveted to the inside of the shell may be used and may suffice amply to support the brickwork when it is built into the furnace, but these narrow ledges cannot in my judgment furnish the sound and substantial support which a body of brickwork two feet or more in thickness receives by resting upon a solid foundation like the mantle.

Moreover the thinness of the inwall seems to have an influence upon the work of the furnace altogether apart from its effect on the durability of the lining. Thin-lined furnaces have been found by their

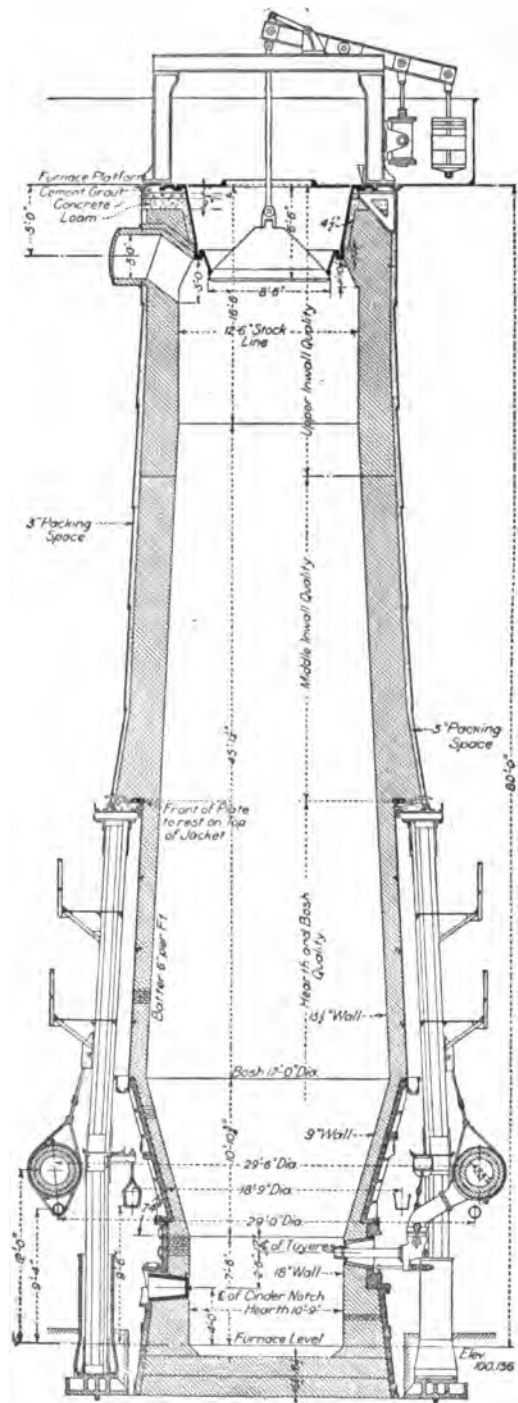


Fig. 174. Section of Northern Iron Company's Port Henry furnace.

managers to be sensitive to the quantity and temperature of the cooling water circulated over the shell and in general to have troubles to which furnaces with linings of normal thickness are not liable, and some of the best furnace managers in the country who have tried them have told me that they had had enough and were perfectly satisfied in the future to return to the standard lining.

Some of the furnaces of the constructions here described, are still in operation and some of them are said to be successful, but as a result of several years of experimentation no standard construction appears to have been developed which all advocates of this type of furnace are willing to adopt, and while the advantages of securing permanence of the lines of the furnace as constructed, of requiring for lining purposes only a small amount of brick, and therefore small expense and loss of time in relining, are undoubted, the essentially unsubstantial character of a wall only about a foot thick, 60 ft. or 70 ft. in height, and leaning inward at the top, may well be questioned. Moreover, the thick lining has the advantage that within reasonable limits it gives the furnace some opportunity to cut itself out to the shape at which it will do the best work, so that minor errors of judgment in the original lines of the furnace may be corrected by the work of the furnace itself within the thickness of the standard lining. This is not possible with the thin one.

The lines of furnaces are not fixed like the laws of the Medes and Persians but shift with almost every campaign to meet changes of conditions or the changed views of their operators. With a lining of standard thickness and a standard shell large enough to contain it, such changes can within reason be made without affecting the shell, but with the thin-lined furnace this is not true. The shell must virtually have a shape exactly corresponding to that desired for the inside of the furnace and if it becomes necessary to change the latter this involves expensive and time-consuming changes in the shell.

For all these reasons, and for the far better one mentioned above, that in practice the thin-lined construction does not seem to have justified itself, it seems doubtful whether the development in this direction will be extensive or at least very rapid.

The Ashland construction. — The construction shown by Figs. 162, 163 and 165 in which the mantle is supported directly upon the tops of the columns, numbering in modern practice from ten to twelve, has virtually been the standard ever since the adoption of the steel-shell construction, but is open to various objections from a practical and operating point of view.

These objections are that the columns come very close to the walls of the bosh and particularly to the outside of the hearth jacket, narrowing up the cooling ditch around the base of the latter and making

the removal of any iron which may run into the ditch in a breakout extremely difficult, because this iron locks itself between the hearth jacket and the columns and in some cases cannot be removed without blasting, which would endanger the columns themselves. Moreover, when this construction is used, the bustle pipe carrying the hot blast to the tuyères has to pass outside the columns, and the penstocks, carrying the hot blast from the bustle pipe to the individual tuyères, have to pass between the columns. These penstocks have to be swung out of the way whenever the tuyères have to be changed, and the columns are greatly in the way at such times. There is nearly always a column close to the tuyère on one side or the other and access to the tuyères is enormously hindered thereby. These columns interfere with the lead of the individual water pipes from the circular water main beneath the bustle pipe to the tuyères and cooling plates and make it difficult to determine which cock controls which pipe, a matter of vital importance in case of a partial obstruction to the flow in one of these pipes, which then requires instant attention as the price of preventing the destruction of the cooling member that it supplies, and the stopping of the furnace to replace the latter.

The writer having realized for years past the seriousness of these difficulties from an operating point of view, when the charcoal furnace at Ashland, Wis., required reconstruction a few years ago, designed it along somewhat different lines, which are shown in Figs. 167 and 175. The central idea of the construction adopted is to remove the columns from their ordinary location immediately under the mantle and set them back far enough out of the way to give complete access to the base of the furnace and to prevent injury to the columns themselves in case of breakouts or other accidents around the furnace.

This was accomplished by building a square framework of extremely heavy plate girders, the inside distance apart of which was slightly greater than the outside diameter of the shell of the furnace. These girders were supported on the top of the four columns to which they were riveted and strongly braced to prevent the possibility of failure by rotation of the structure about its vertical axis. The shell was supported on these girders by eight brackets, two on each girder, these brackets being heavily riveted to the shell.

In order to prevent the sagging of the mantle plate eight cantilever brackets projected in under the mantle, one vertically under each of the main brackets. These were supported by a downward extension of the main angles which fastened the main brackets to the shell and the outer ends were held down by struts extending down from the ends of the main brackets.

The construction was a success in all respects and gave a degree of accessibility and convenience in operation around the bottom of the

furnace beyond comparison greater than that of any other type. This accessibility is indicated by Fig. 175, which shows two men abreast, standing shoulder to shoulder inside the column, and outside the outermost point of the penstock. Of course, the tuyères do not come in line with the columns in this construction any more than in the ordinary one.

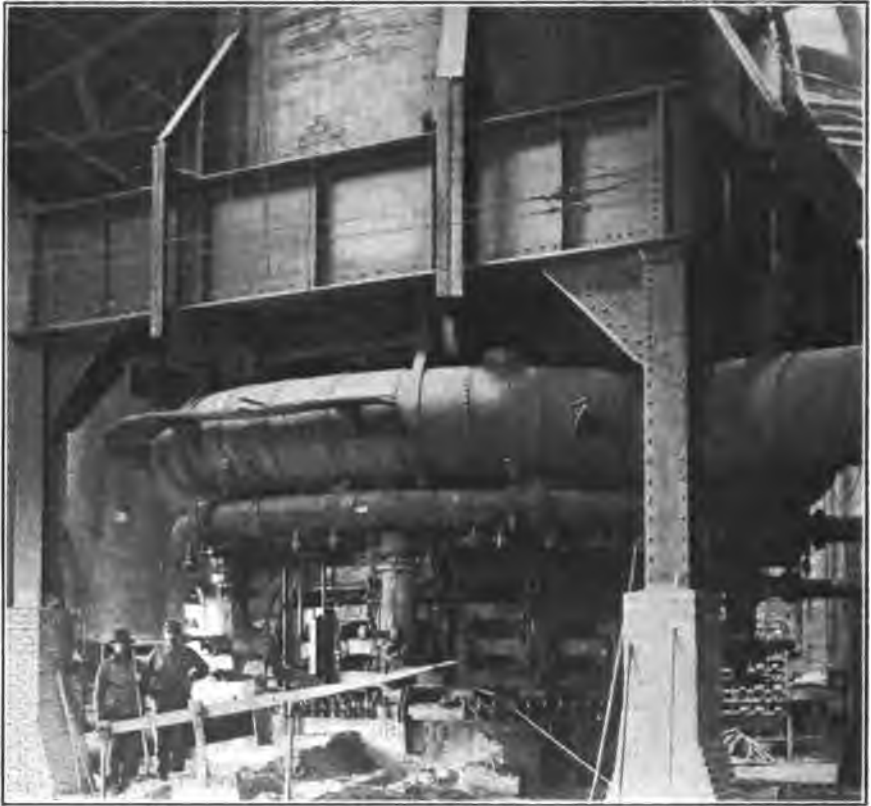


Fig. 175. Ashland construction.

For a furnace of this size no change in the design of the construction need be made. For a coke furnace of greater size and with greater liability to serious difficulties of operation, it would probably be desirable to use five columns, so that if one of them were to fail three of the girders, encircling more than one-half the furnace, would still stand and support it. This, of course, would only happen in case of a terrific disaster because the columns are set back so far from the furnace that no ordinary accident could affect them, and on account of the abundant room around them they can be thoroughly protected by brickwork.

In case this construction were used for a coke furnace a box girder would be used instead of the single plate girder and this box girder would be made water-tight and serve for the circle pipe to supply cooling water around the furnace. This would prevent any possibility of the girders being softened or affected by heat no matter what happened.

This construction permits the bustle pipe to be put inside of the columns and thus to have the penstocks as close to the tuyères as may be desirable without having any interference between the penstock and the columns. This also shortens up the bustle pipe materially, which reduces both its weight and its cost. One of the important features of this construction when used to replace the standard type, is that the foundations, lying entirely outside those of the old construction, may be put in while the latter is being torn out, and the structural work may be erected before the old furnace is down, as was done in the case illustrated, with the saving of many weeks in time, worth many thousand dollars more than the slight additional cost of construction.

Firebrick. — There is scarcely any feature of the construction and operation of the blast furnace of more importance than this and probably none concerning which less is known by the great majority of those to whom it is so important, the furnace managers.

The problem of firebrick has never been solved in terms of chemistry, or if so the solution is not known to furnacemen. This is probably because several other factors, such as the fineness of the grinding of the clay, and the method by which it is molded, the temperature and time of burning of the bricks, and other factors not reflected in their analysis, have a vital influence on their character.

For this reason firebrick are to a great extent bought and sold on the basis of workmanship, freedom of the bricks from warpage, and general reputation. It is true that iron and alkalies in more than moderate amounts are barred because both unite with the silica at low temperatures and cause the fluxing of the brick under conditions far less severe than can be met with impunity by bricks free from these impurities. But further than this chemistry does not play a heavy rôle in the purchase or sale of firebrick.

It was customary a generation or more ago to use very large bricks, a size 6 in. square on the small end, by 9 in. or 14 in. long was the standard in certain of the older iron-producing regions. But this was followed by a period in which a thickness of about $2\frac{1}{2}$ in. became standard, virtually the same as that of red-brick. These were made in lengths of 9 in. and $13\frac{1}{2}$ in. so that two of one would equal three of the other. The straight, commonly known as the "square" brick, is $13\frac{1}{2}$ in. long, 6 in. wide, or in the case of the tapered or circle brick,

known as "keys," 6 in. wide at the larger end. Similarly the straight brick, 9 in. long, is $4\frac{1}{2}$ in. wide, and the "keys" $4\frac{1}{2}$ in. wide at the large end.

These are relatively small bricks and require much labor for laying and involve a great number of joints, but it was claimed by some furnacemen for many years that thicker bricks could not be burned satisfactorily, though I have seen years ago thousands of brick 6 in. thick which gave complete satisfaction in the furnaces in which they were used, which were small coke furnaces.

In very recent years firebrick manufacturers began to make furnace bricks 3 in. thick, and these are very much freer from warp in the burning process than the thinner bricks as well as requiring less joints and less labor to lay them. They are, therefore, very much to be preferred from practically all points of view except that of cost.

In this respect the brickmakers have established certain customs which have not been permitted to any other trade. The standard price of bricks is based on the 9-in. by $4\frac{1}{2}$ -in. by $2\frac{1}{4}$ -in. brick. Smaller bricks than the 9-in. are charged for at the same rate per brick as if they were the 9-in. size. This is explained by the brick maker on the ground that the clay in the brick amounts to very little but that the workmanship on it is just as much on the small brick as it is on the large one. The $13\frac{1}{2}$ -in. bricks, on the other hand, take a price of nearly 20 per cent. higher than the 9-in. based on the same volume.

When he is asked why this is so the brick maker replies that they are more difficult to handle and to burn.

Similarly when it comes to the 3-in. lining instead of the standard thickness, the brick maker insists that he must have an increase of about 20 per cent. in the price per unit of volume of these, although warp in this case is very much less, the labor decidedly less, and the burning but little more.

It is, however, no more than fair to the brick manufacturer to say that quality does not always receive the consideration from the furnaceman that it should, and the manufacturer of a superior grade of brick is often forced to compete against a poor grade of brick on a piece basis, which is neither fair nor sensible, but is to a large extent the outcome of the difficulty in determining what real quality is, already described.

Firebrick are made in three grades known respectively as "hearth and bosh," "inwall," and "top," intended for use in those regions of the furnace for which they are named. Formerly the "hearth and bosh" quality was usually continued a number of feet above the top of the bosh, but in the best recent practice this quality stops at the top of the bosh.

These differences in quality are adapted to meet the difference in

conditions in the different portions of the furnace. In the hearth and bosh there is little or no abrasion but intense temperature, and intense scouring action of slag and iron. To meet these conditions the bricks are made with a relatively large proportion of flint clay and a correspondingly smaller proportion of plastic clay. These bricks are not exposed to much abrasion and are therefore not particularly designed to resist it, but through their composition and burning, are made to stand extremely high temperatures successfully.

In the middle zone of the furnace in which the lining is known as the "inwall" the conditions of temperature and chemical action are considerably less severe, while those of abrasion due to the presence of some of the solid portions of the charge and the sand-blast action of its fine portions at the velocity imparted by the blast are important, and the cone in this portion of the furnace being convergent upward the sand-blasting action is a factor to be reckoned with, whereas in the bosh with its divergent upward flare this is not the case. Inwall bricks, therefore, are made with more plastic and less flint clay than hearth and bosh brick to meet these conditions. At the same time they still have high heat-resisting qualities.

At the top the conditions of abrasion are extreme, as has already been described, while the temperature in good practice in this zone of the furnace is generally below 1000°, so that the necessity of refractory character in the lining of this zone can be to a certain extent neglected, or at least need only receive an insignificant amount of attention as compared with what it demands in the lower zones. For this purpose the bricks are made with a large proportion of plastic clay pressed very hard, and burned to a great density, some of them resembling what is known as vitrified paving brick almost as much as they do firebrick, and for the same purpose, resistance to abrasion.

Where no form of stock-line protection is used such as those described above or an equivalent, the quality of the top brick is fully as important as that of the hearth and the bosh brick, since top bricks which do not resist abrasion permit the stock line to be gouged out by the drop of the stock from the bell, with the result that the correct distribution of the stock is made impossible and becomes largely haphazard, this is necessarily followed by extremely bad operation in the lower portion of the furnace, with the result of poor quality of iron, or high fuel consumption, or both. For this reason the necessity of repairing the stock line has in the past been responsible for an appreciable percentage of all the cases in which it has been necessary to blow out for repairs, though the fact may not have been apparent in all cases, because when a furnace which has been working well gradually begins working worse and worse, it is commonly and in general rightly, assumed that the lining is too far gone to permit it to do further

good work, and without any analysis as to the location of the wear which is responsible for the bad work, it is generally attributed to the inwall, although the top may be the part to blame.

It is unfortunate that more exact and accurate knowledge is not at hand on the subject of firebrick and their suitability for lining purposes, but the problem is so complicated that a complete analysis would be possible only after years of experience by an organization which contained both an experienced firebrick maker and experienced furnacemen, a condition which has seldom if ever existed.

The firebrick manufacturer has, therefore, to adapt his product to the conditions described by the furnaceman, and the furnaceman has to use the brick furnished to him by the brick maker in the prayerful hope that they will give the results desired, but in the vast majority of cases without any better foundation for this hope than his confidence in a given brand of brick, and perhaps his belief that a certain brick maker understands the conditions well enough to provide him with a suitable lining.

It is greatly to be desired that the furnaceman and brick manufacturer should meet directly rather than through their respective selling and purchasing agents. By discussing frankly and without prejudice their respective objects and difficulties progress would be made in real knowledge of this subject with resultant benefit to both.

I have already described the enormous change in the furnace conditions which began in the middle nineties. The greatly increased outputs and the vast increase in percentage of fine ore used in the burden, in combination with the introduction of mechanical charging brought about conditions under which the lining problem seemed to be almost insoluble. I know on the best authority that one of the largest brick makers was desperate at one time over the situation and would have been glad, had he felt that he could afford to do so, to surrender the furnace-lining portion of his business.

It seems extremely likely from the information which has been developed within recent years concerning methods of charging, that these have been more responsible for unsatisfactory life of linings than was the poor quality of the linings, in many cases in which the firebrick manufacturer had to take the blame.

It has long been known that bad filling would rapidly destroy a lining by channeling, but certain types of mechanical charging which are theoretically correct produce conditions in practice under which it would be impossible for any lining to survive for any considerable length of time.

This matter really belongs under the subject of stock distribution and will be treated at greater length in an article on that subject.

The laying of the firebrick. — The mortar used for this purpose con-

sists of ground fireclay which is mixed to grout of a consistency to suit the ideas of the furnaceman or the boss bricklayer, and usually kept hot during the mixing and to a considerable extent even during laying, by a steam coil in the bottom of the clay box.

This grout or mortar is generally mixed quite thin, poured onto the brickwork with a large dipper and flushed into the joints of the brickwork, both from below by sliding the brick being laid up against the one just laid, so as to fill the joint as nearly as possible with fireclay, and then from above by filling in the space and working the fireclay down between the two bricks with a trowel if any opening sufficient for that purpose exists, which in general it should not do.

Many of the difficulties with linings have been attributed by some furnacemen to bad bricklaying and particularly to wide joints. Some go so far as to insist that all unevenness must be removed from the bricks by chipping each individual brick where any appreciable amount of warpage exists, producing what is known as a case-knife job. This means that every joint shall be laid so close that it is impossible to get the point of a table knife into it.

Thick joints are undoubtedly very bad, but I have never seen any results produced by such extreme precautions which seem to me to justify the very greatly increased expense in laying the lining by this method. Careless work should on no account be tolerated, and if joints are found which are not thoroughly flushed the brickwork should be torn down and rebuilt properly. But as long as the firebricks themselves are made of clay suitably burnt, it has never been evident to me why the clay in the joints should not be burnt practically into the same structure as the brick itself, and in fact the brickwork which is torn out during the relining periods from the lower portion of the furnace where the heats have been high, comes out in blocks the line of whose breakage frequently pays little or no attention to the original joints in the brickwork, proving to my mind that when properly laid, the fireclay joint becomes, by the action of the furnace itself, almost as good as the brickwork.

This statement is, of course, predicated on the assumption that fireclay of the same quality as the brick will be used. If inferior clay be substituted it may act as flux for the brick themselves and absolutely destroy the lining.

The practice of making the fireclay thin may, in my judgment, easily be overdone, for the reason that if the clay is very thin, when the bricks are settled to place with a mallet, if there is the least particle of warpage, the brick gives enough to throw the thin clay out of the joint and when it springs back to shape again this joint is practically open. When the fireclay is made so thick, on the other hand, that it will just about pour from the dipper, it is too plastic to permit

this action and while the bricks may be driven up to a solid bearing with one another, the slight joint which remains after they are in contact is fairly filled with fireclay.

The filling of the packing space. — In former times when furnace shells were built not much more than a quarter as strong as they are to-day they were frequently burst by the expansion of the brickwork within them and it was therefore universal practice at one time to provide a space of 3 in. to 6 in. between the outside of the brickwork and the inside of the shell which was filled with some yielding material to allow for the expansion of the brickwork, and yet continually resist it. In modern practice, shells are so strong that they can resist the expansion of the brickwork and the latter is therefore laid up close to the shell and the small space necessary as a construction allowance is quite frequently grouted with concrete which, of course, is entirely unyielding. This means that the shell must be strong enough to resist the expansion of the brick or else it must stretch enough to accommodate the expansion of the brick within its elastic limit. Probably both these actions take place to some degree, but in any event this plan is not safe except with a shell of the strongest and best construction. If the brickwork were laid up tight inside a shell of older type the latter would be burst within a short time, as unfortunately has happened only too often even with the greatest precautions.

To prevent this is the reason for the custom, with such shells, of leaving a space between shell and lining and filling it with some material which is yielding and yet to some extent resistant, mentioned above. The necessity of resistance arises because if an open space were left between the brickwork and the shell the internal pressure would push the brick back, break the bond, and ruin the keying, so that some bricks would be likely to fall out, which would start a hole in the lining, and once started this would rapidly enlarge itself so as to destroy the lining. The bricks therefore must be held up to their places by some sort of filling between them and the shell.

Some furnacemen prefer for this purpose clay, but clay is only slightly compressible, and I prefer pumice cinder, made by running a light slag on to wet ground, or into a tank of water. The steam formed by the heat of the slag puffs the latter up into a huge sponge whose total volume is many times the volume of the slag from which it is made. As it is crushed under pressure its volume becomes smaller and smaller by the progressive destruction of the cells, first of the larger and then of the smaller sizes, but the material maintains its resistance to compression almost constant throughout a very great diminution of volume.

These are the conditions which we have to meet, as brickwork, unless rigidly bound, does not expand elastically like steel, but when

expanded retains its new size, never contracting, or never to anything like the degree to which it had previously expanded, so that as its temperature varies it undergoes a slow but constant growth. Thus a furnace shell may be amply large at the beginning of a campaign and for several months or a year, but gradually, as the lining increases in size, when all the compressibility of the backing is gone, the direct force of expansion of the bricks is transmitted to the shell, and while the steel is stronger than the brickwork inch for inch, the latter is so much greater in area in any given section of the furnace that it generally bursts a thin shell when the "give" of the backing is gone.

In order to make the backing gas-tight the pumice cinder is sometimes mixed with clay, but this has the effect of reducing its compressibility especially as the clay is apt to burn hard after the furnace has been in operation for a while, and this therefore limits the amount of compression which a given portion of the backing can undergo without exerting undue stress upon the shell.

Drying the lining. — Even with the best possible practice several tons of fireclay are used in laying the lining of a furnace, and this being mixed with something like an equal weight of water there is a great quantity of water in the lining when the brick laying is finished. This is capable of doing great damage and should therefore be removed by thoroughly drying the lining before the furnace is put into operation.

Various methods are in use for this but usually a temporary brick oven is built immediately in front of the tapping hole, and communicating with the furnace through it. The bell is closed and draft produced either by opening the bleeder or allowing the main draft stack to draw on the furnace through a stove. A fire is built in the temporary oven and the gas from this passes into the furnace and warms it up, drawing out the moisture from the face of the brickwork first, and gradually as the heat works through drying out the whole mass quite completely.

The hot gas also acts as a carrier for the steam formed from the moisture and takes it out of the furnace. This drying-out process lasts anywhere from one to three weeks according to the judgment of the furnace manager and the state of the iron market.

There is no doubt that the operation is much better carried on slowly than rapidly, but a very moderate rate of firing will bring the warmth through a wall of 2 ft. or 3 ft. thickness in the course of three or four days, and a week of this treatment is in general sufficient to dry out the clay about as thoroughly as it can be done by this method. Of course, if the furnace is ready for operating before the rest of the plant, it is well worth while to continue the fire for drying out for two or three weeks or even longer if convenient. But in my judgment three-fourths of all the benefits to be obtained by drying will be

obtained in the first week of moderate but steady firing, day and night.

The removal of this moisture not only prevents the possibility that the rapid heating which would come from the actual operation of the furnace on a green lining would convert the moisture of the fireclay into steam so fast as to drive the clay out of the joints, and perhaps blow objectionable holes through the packing at the back, but it also eliminates the very objectionable effect of moisture on the operation of the furnace while blowing in, when it is already very cold by reason of the fact that its initial charge is not preheated in its descent, but necessarily cold clear to the bottom.

I have never had any experience with blowing in on a green lining, but I should expect that much more fuel would be required for the first two or three days of such blow-in than would be required on a furnace with a thoroughly dried and warmed lining, and that the difficulty and delay in getting the furnace into normal operation would be much greater.

Bustle pipe, penstocks and blow pipes. — The hot blast is delivered from the stoves through the brick-lined hot-blast main to a circular distributing pipe surrounding the furnace which is called the bustle pipe. This is a complete annulus of heavy steel pipe lined with firebrick, surrounding the furnace concentrically (see Fig. 175). It is commonly supported directly on brackets on the furnace columns or suspended by hanger bolts from heavy brackets riveted to the shell. The latter method is much to be preferred as the pipe is a massive structure and when it expands and contracts from changes in temperature is capable of exerting great stresses. If it is supported on swinging hangers, it can move without doing any damage, but if supported in the furnace columns, it not only puts an eccentric load on them by its weight, which is bad enough, but may exert a direct lateral thrust of much more serious amount.

It is well to note here that the bustle pipe is a far heavier structure than its appearance would lead one to expect. The one here shown for a small furnace weighs about 50 tons and one for a large furnace might easily go to 150 tons. The brick lining of the bustle pipe is laid in two courses of circle brick made for the purpose. On account of the double curvature and the brick cutting which this necessitates, the labor of laying up the lining is very great; nevertheless it is of the utmost importance that the work be well done.

The heat losses by conduction and radiation are very serious in spite of the firebrick lining, and in recent years several furnacemen have tried making the outer portion of the lining of bricks or blocks made of infusorial earth or kieselguhr, whose conductivity is only one-tenth that of firebrick. This material is too soft to withstand

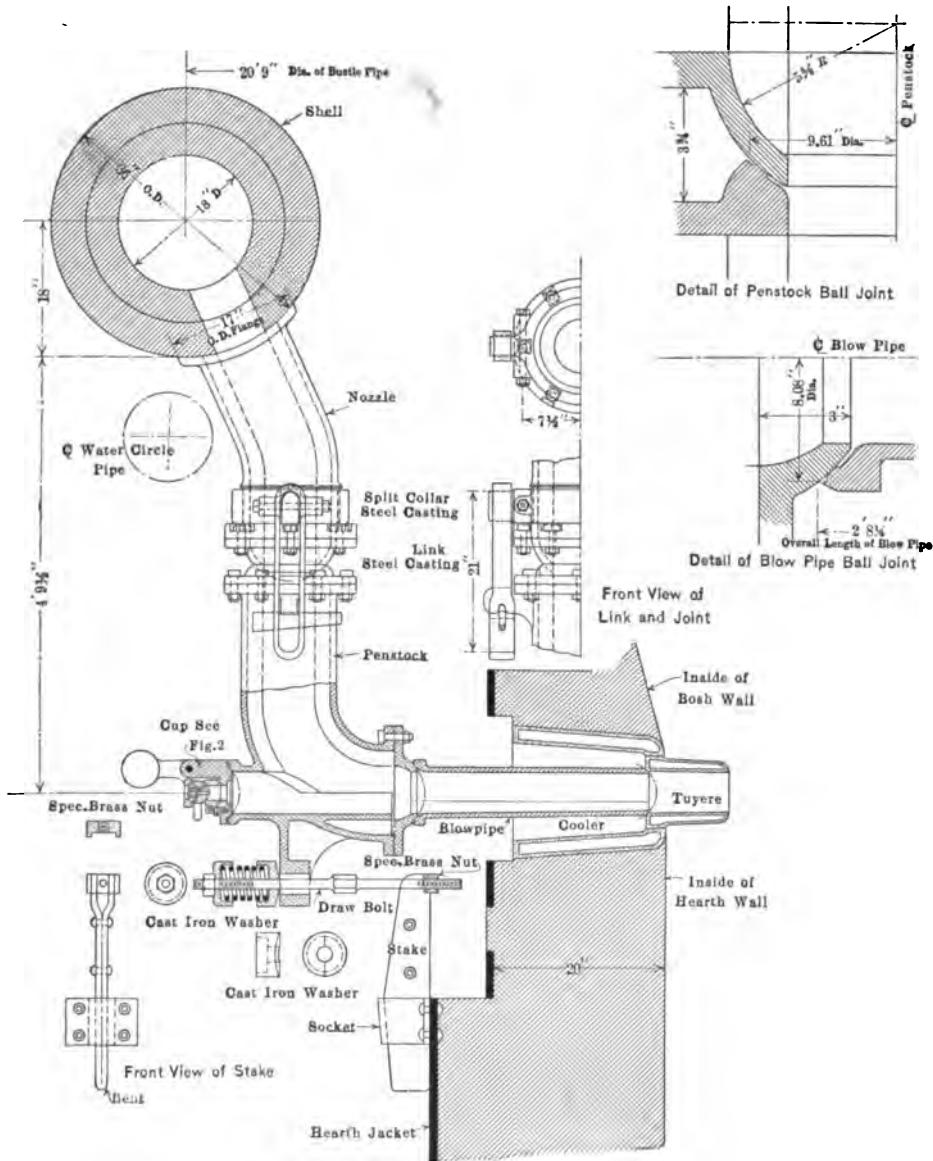


Fig. 176. Bustle pipe penstock and blow pipe.

the mechanical wear on the inside of the pipe so must be protected by a course of firebrick next the blast. Conduction losses have been greatly reduced by this practice, and it is destined to grow in favor. This applies of course to the hot-blast main as well as the bustle pipe, which is only the extension of this main.

The blast is delivered from the bustle pipe to the individual tuyères by connecting pipes called the "penstock" and "blow pipe." The design of these is very important in the practical operation of the furnace for the reason that whenever a tuyère is to be changed — a more or less normal occurrence even in the best practice, and an onerously frequent one when the furnace is in trouble — the connecting pipes must be removed before, and replaced after, the tuyère is changed, and it is vital that this should be done quickly.

Many designs have been used from time to time, but certain general principles have been developed, and a very satisfactory design in which these were applied is shown by Fig. 176. The walls of the hearth and tuyère zone, with the bands and jackets surrounding them, are clearly shown on the drawing. The cooler is a hollow, conical, bronze casting shown in section; water circulates vigorously through the hollow space, being delivered to it and taken from it by pipes entering at holes tapped in the butt, not shown on the drawing. The inside of the cooler has a slightly raised strip at its inner end cast to a true surface and into this fits the tuyère, which is a hollow bronze casting similar to but smaller than the cooler, and provided with a raised strip at its outside end, which is a close fit in the nose of the cooler, as shown. The tuyère is cooled by circulating water exactly the same as the "cooler."

The purpose of the cooler is to supply a protective, more or less permanent support for the tuyère, which projects, as shown, bodily into the furnace from 6 to 15 inches, depending upon the practice, the size and condition of the furnace, and the opinion of the furnaceman.

The blow pipe is of cast iron turned to a ball joint at both ends. At the front end, the ball fits in the butt of the tuyère, which is bored to a ball joint to fit it, while at the back end is a female ball which takes the projecting ball on the end of the penstock or "bootleg" as it is sometimes called.

Ball joints are universally used because the tuyères do not always go into the furnace the same distance, and even if they did, the expansion of the hot-blast main is more than likely to throw the bustle pipe more or less off the center of the furnace. By having ball joints, these variations in the relative position of the tuyères and bustle pipe, both vertical and horizontal, are taken up and a perfect joint quickly and easily made.

The penstock is in the general form of the pipe-fitting called a "sweep tee." The sweep turns towards the tuyère and the opposite (smaller) end is closed by a cap. The penstock is separate from, but supported by and makes a tight joint with, a nozzle riveted to the bustle pipe. The planes of the ball joints should always be at a right angle to one another so that swinging the penstock in or out to com-

pensate for a difference in the location of the tuyère may affect the vertical alignment as little as possible and swinging the blow pipe up or down affect the horizontal alignment as little as possible. In many cases the penstock is designed to run on a diagonal, but this is exceedingly bad practice because an adjustment in one direction cannot be made without simultaneously affecting that in the other direction, and this greatly increases the difficulty of making both joints quickly and perfectly.

The ball joints are not held together by bolts in the ordinary way because all parts of the hot-blast system become heated to a high temperature and flange bolts under those conditions would become practically unworkable; moreover, even if they worked, they would be extremely slow, while haste is a vital condition in changing tuyères. The horizontal joint at the top of the penstock is held together by steel yokes suspended from lugs on a steel ring resting on the flange of the nozzle, but independent of it, so that it can be turned in any direction without difficulty. This ring is made into two halves, and bolted together in order to get it around the pipe above the flange, and the back or upper side of the flange is turned off, as is the base of the ring, so as to facilitate this turning when it is required. The steel yokes are provided at the bottom with keys which engage heavy lugs cast on the sides of the penstocks near the top. These keys can be operated quickly and easily with a hammer, and practically as well when hot as when cold.

The horizontal ball at the base of the blow pipe is held to a joint by a long bolt with a right-hand thread on one end and a left-hand on the other, one end of which pulls against a steel stake set in a socket in the hearth jacket, the other end pulls against a heavy lug cast on the bottom of the penstock. The bolt operates through a heavy coil spring set between washers so that contraction and expansion of the penstock and blow pipe due to changes in blast temperature will be automatically taken up, the pressure of the spring being sufficient to make a tight joint at the base of the blow pipe against the pressure of the blast. Brass nuts are used on the draw bolt so that rusting will not make them difficult to operate. The draw bolt is far enough away from the blow pipe not to become heated and so remains easy to operate.

In case of serious trouble with the furnace, it is sometimes desirable to be able to release the blow pipe from the tuyère instantly so that the slag can be flushed out through the latter. This can be done in the design shown by prying the inner brass nut over the upper end of the stake. Then if the keys in the links, which hold the upper joint, have been slacked, the penstock will swing back under the pressure of the blast and the blow pipe will fall out of itself, opening the tuyère completely.

The penstock is lined with circle brick 2 inches thick, made for the purpose, and fitted to place. The ball joints at the top and bottom of the penstock are made separate from the penstock proper and bolted to it so that in case they are scarred or warped in use, they can be taken off and be replaced with others. This should not occur except at long intervals, and therefore bolts are used to hold these in place. Incidentally it is very much easier to turn a ball joint on a loose flange like this than it would be if it were cast solid on a crooked casting like the penstock. This construction has the further advantage that the ball flanges hold the brick lining firmly in place. It will be noticed that the female ball joints have a very narrow bearing surface, and that this is protected from an accidental injury by being below the line of the end of the ball casting.

The Wicket. — The rear opening of the penstock is provided to give access to the tuyère for cleaning out and for plugging with clay in case of a stop, or the like. The cap which closes this opening is called the "wicket." This joint also is made spherical so that the cap will be tight in any position and is held in place by key bolts which can be operated with a hammer in spite of being very hot when in use.

The wicket is provided with a small hole through which a pricking rod can be run to punch out the tuyère, and this hole must be kept shut by some apparatus which permits it to be opened freely and which contains a peep glass through which the action of the tuyère can be directly observed. Much ingenuity has been expended in meeting these conditions. The wicket design here shown gave good satisfaction, which is more than can be said for many that have been used. The outside end of the hole through the wicket is turned to fit a ball of 3-inch diameter. This ball is loosely held by two pins which go into holes in its sides. These pins are at the lower end of an angle lever which has heavy weights cast at the ends of its horizontal branches. These force the ball up against its seat in the wicket, and the ball being loosely held is free to take a position which makes a tight joint. The pressure is applied to it, not through the pins, but by a loosely fitted cap which is a part of the weighted lever. The hole in one side of the ball is square and the end of the squared pin on that side fits loosely into it. The outer end of this pin is bent down into a handle so that the ball can be rotated on the horizon axis transverse to the line of the tuyère. The ball has a half-inch hole bored through its inner half and a larger tapped hole through the outer half with a squared seat at the bottom. In this tapped hole fits loosely a screw plug with a half-inch hole through it. This is screwed down on to a glass set in the base of the larger hole and holds it firmly in place. Normally the ball is turned at right angles to the position shown and its blank face is presented to the seat, when it is desired to look

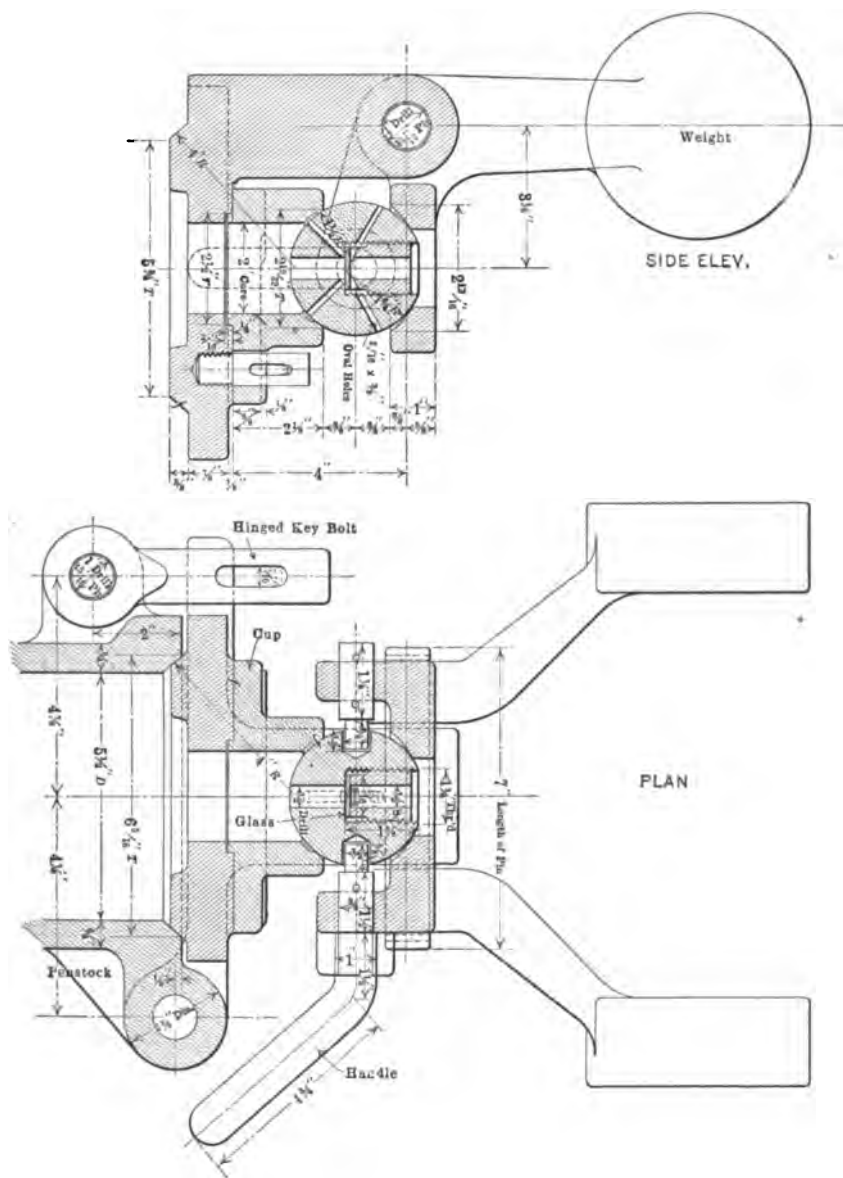


Fig. 177. Wicket.

into the tuyère, the ball is rotated by turning the handle a quarter turn so that the peep hole through the ball is in the axis of the blow pipe. The reason for this is that at all furnaces, but especially charcoal furnaces, the gas leaking back even for a few seconds when the blast is off, clouds up the glass so that after a short time it is impossible to see through it. By this design the glass is only exposed to this

action when the blast is on the furnace for a minute or two at a time. In addition four holes are drilled through the ball in such position that by turning it to different angles a strong jet of blast may be blown through these holes to impinge on the glass in such a way as to blow it clean. By turning the blank side of the ball to the seat, the sight glass can be changed with the blast on the furnace. The hole through the wicket is unnecessarily large in this design and exposes the ball to too great a pressure. The design could be improved by making the hole smaller and putting the joint surface next to the hole instead of at the outside so that the area of the ball exposed to the blast pressure could be reduced to a small fraction of that in this design, then the same weights would keep the joint tight against a much higher pressure.

This design of penstock wicket, etc., was made under the supervision of the writer to fit the conditions of a small furnace which was being reconstructed. While the general design is right certain details worked out badly owing to some conditions which could not be altered. The first of these was that the vertical leg of the penstock was too short, and the inner end of the penstock was about a foot too close to the furnace, the blow pipe being as much too short, so when swung back it did not give as much room to work as was desirable. If the vertical leg had been 2 feet longer so as to give a proportionately greater swing, it would have been very much better. These defects were due to the location of the bustle pipe and the openings through it, which we did not desire to change. In a new plant these difficulties could be avoided, while using the general principles of this design, which are, in my judgment, correct.

Since these wickets were made, I have seen in use a simpler apparatus which obtained the same general result and gave good satisfaction. This design is in essence a large plug cock mounted in the line of the hole through the wicket and arranged to open or shut the hole exactly as a plug cock does. It was found that by making the taper of the plug just right, the tendency to bind, due to unequal expansion, could be overcome. I would have supposed that this scarcely could have been done, but this simple arrangement seemed to work very well. I saw it at the Lorraine blast-furnace and I believe it was the design of Mr. A. J. Boynton, the superintendent of that plant.

It may be thought that too much stress is being laid upon these details, but as a matter of fact there is scarcely anything which has a greater influence on a decent, orderly and successful operation of the furnace than these parts. If a correct design be not used, a tight joint cannot be made, or if it be tight when made, as soon as the parts become heated in operation it is no longer tight and the blast howls out at every leak in a way that is distressing to the ear and apt to be ruinous to the cost sheet.

CHAPTER VII

CLEANING AND WASHING THE GAS

THE realization of the great heating value of the top gases of the blast-furnace was very slow in taking useful shape. For centuries, furnaces ran with their tops wide open, discharging the gas into the air, with which it united in a great column of flame, visible for miles by night, even in the small furnaces of that early day.

Even after the invention of the steam engine, the possibilities of blowing furnaces by steam power were not practically realized for several decades and furnaces continued to be located primarily with reference to a suitable water power for blowing. In the same way after the invention of the hot-blast in the third decade of the nineteenth century the stoves were not at first heated by gas from the furnace, but were independently fired with coal.

Later a small chamber filled with iron pipes was built over the top of the furnace and the flame from the open top passed up through this, heating the blast which passed through the pipes. Still later flues were built into the brickwork near the top but just below the stock line and connected with a powerful chimney whose base was approximately level with the top of the furnace; this chimney drew some of the gas from the furnace, naturally much mixed with air drawn in from above, and the mixture burnt on its passage from the furnace top through the boilers and stoves to the chimney.

The final step was taken by closing the top of the furnace with a bell and forcing the gas by the pressure from below out through the flues into a pipe leading down to the ground level, where the stoves, boilers and stacks were located as previously described. This pipe early received and still retains the name of the "downcomer."

These top gases in Lake ore practice contain about 50 per cent. of the total thermal value of the fuel charged. In districts where leaner ores are used and more fuel is consequently required per ton of iron the gas is correspondingly richer and contains a proportionately larger percentage of the thermal value of the fuel. In Lake ore practice an average analysis is about as follows: carbon monoxide $25\frac{1}{2}$ per cent., hydrogen 3 per cent., carbon dioxide $12\frac{1}{2}$ per cent., nitrogen 59 per cent. The thermal value comes entirely from the first two components.

The hydrogen comes partly from the moisture in the blast which is dissociated in the hearth, and partly from the moisture of the charge which is decomposed in the upper levels of the furnace. This gas

under standard conditions of 32° F. and 30 inches of mercury contains from 94 to 102 B.t.u. per cubic foot and has a specific heat of about 0.02 per cubic foot, so that it contains about 2 B.t.u. of sensible heat for each 100° F. above that temperature.

This gas is then somewhat more than half as high in heating value per cubic foot as ordinary producer gas. This, with the enormous volume produced (some 140,000 cu. ft. per ton of iron in good practice and more where the practice is poorer), give it enormous commercial value, so great in fact as to equal a considerable percentage of that of pig-iron itself.

This gas having been in intimate contact with the charge in its course up through the furnace, and having carried off all the moisture of the charge not dissociated, necessarily contains much moisture and picks up much fine dust from all the different components of the charge. It also carries a fume consisting of solids volatilized in the hearth of the furnace which sublime into the solid state, in the form of an impalpable powder, as the gas cools in its progress toward the furnace top.

It is this fume that gives the gas its characteristic appearance, so that an experienced furnaceman can tell more quickly by looking at the gas discharging from the boiler and stove stacks than by any other way if his furnace is working "hot" or "cold," since a relatively few degrees drop in hearth temperature make a great difference in the amount and appearance of the fume thrown off.

This fume consists mainly of silica, alumina, lime, potash from the ash of the coke, and iron, and in case the charge contains much manganese, this element is present in the fume to a great extent, changing the white color of the fume of a good-working furnace on ordinary iron to a light yellow when running on "spiegel" and to a heavy yellow or brown when running on ferromanganese.

In the early days of slow driving the velocity of the gas current through the furnace was small and the quantity of fine ore in the charge was almost negligible in comparison with the quantity of fine ore used to-day, which runs from 50 to 100 per cent. Mesabi in the majority of American practice.

Under those conditions a single, comparatively small outlet at one side of the furnace top was sufficient and the quantity of dust carried by the gas was extremely small, therefore a single pipe of moderate size running straight or almost straight down and branching directly off to the stoves and boilers was all that was necessary to handle the gas. This constituted but a small, almost an insignificant fraction of the plant as a whole. Conditions at the present are vastly different from this in three respects:

First, the velocity of the gas through the furnace is several times greater than it was in those early days. The carrying power of the

fluid current increases at an enormously rapid rate with an increase in velocity. I have seen the statement that this increase was as the seventh power, which would mean that doubling the velocity would increase the quantity of material carried 128 times. Whether this be true or not it is certain that the rate of increase in carrying power is extremely high.

Second, the ore used instead of being practically all hand-prepared lump consists very largely of fines, much of which is capable of passing through a 100-mesh sieve.

Third, we have come to realize the enormous cost of attempting to utilize gas in its dirty condition for stoves and boilers, even leaving out of consideration gas engines which require for their successful operation gas cleaner than the air we breathe.

These three causes have had an enormous effect on the gas-handling system of the furnace, which has in recent years become one of the largest and most conspicuous features of the whole blast-furnace plant.

The outlets from the furnace top. — From the time of the closed top or soon thereafter, some furnacemen claimed that the gas should be taken off either from the center of the furnace or at several points symmetrically arranged around the furnace top. Others claimed that the gas, having gone through the stock column, had done its work and that the location of the outlet was a matter of no importance, and that one large outlet located on one side was cheaper and simpler than any other arrangement and just as good.

In connection with furnace tops, I have shown a design of top arranged to take the gas out at the center, which worked successfully for many years and gave but little trouble. It was, however, impossible to make the top quite so simple in this way as with the outlet on one side, and so the great majority of furnaces built in the United States up to twenty years ago were constructed on the latter plan, although in discussing operation I shall show what is to my mind an indisputable proof that a single side outlet produces an unsymmetrical passage of the gas through the furnace and cannot lead to the best work.

As furnaces and their outputs grew they produced a vastly larger quantity of gas, so their designers provided more gas outlets, two and even up to five or six. Good practice now very generally uses four, though in my judgment three properly located are sufficient.

Downcomers. — This introduction of multiple outlets introduced other difficulties into the design of the plant.

With a single outlet the downcomer could drop almost vertically to the ground close to the base of the furnace, but with this growth of output, necessitating multiple outlets, came the vast increase of dust which I have mentioned and the necessity for providing some means for its removal. As long as the gas traveled on a steep down-

ward slope the dust would accompany it, but when the dust reached the horizontal passages leading to the stoves and boilers, and from these to the stack, it settled in them and obstructed them so rapidly as to constitute a serious obstacle to continuous and satisfactory operation.

Means therefore had to be provided for the removal of the dust at the foot of the downcomer and for this purpose chambers, at first only a little larger than the gas mains were introduced, but as conditions grew worse and worse these were increased in size and required therefore to be placed further from the furnace in order to give the necessary room for operation.

This threw the foot of the downcomer away from the furnace at its base, while the necessity of reaching more than one outlet threw its top back from the closest point on the top of the furnace shell, to the center line of the shell when two outlets were used, and finally to the back or opposite side when four or more were used. These two factors flattened the slope of the downcomer from almost vertical to a slope well below 45°.

In some of the earlier installations these conditions were made still worse because it was considered necessary to have the downcomer enter the top of the dust catcher in the center of the latter and this reduced the vertical height at the same time all the other factors above mentioned increased its horizontal reach. I think that the slope of the dust catcher on some of the plants built about the time of the Duquesne revolution was not more than 30°. These were extremely unsatisfactory in operation because not only would dust lodge in them but also coke and other materials from the charge; they did not free themselves under any circumstances and no matter how large they might be built, they filled up until the velocity of the gas through them was great enough to scour a passageway through the accumulation on the bottom slope, this of course involving high top pressure and consequent leakage on every joint not tightly sealed.

Explosion doors.—Downcomers are generally provided with explosion doors for two purposes: First, when furnaces are stopped it is almost impossible to prevent air being drawn into the gas main at some point or other. This air mixes with the gas and produces an explosive mixture. When operation is resumed this mixture is ignited at the boiler or stove burners and an explosion follows which in some cases is violent enough to burst the main, dust catcher and downcomer unless it is relieved by suitable safety-valves or explosion doors.

Second, the furnace itself is liable to slips or explosions in which a pressure of several pounds to the square inch, ordinarily only occurring at the lower levels of the furnace, reaches the top and would do it great damage unless properly relieved.

This later theory has been combatted by Mr. Julian Kennedy who has claimed that explosions were more violent in proportion as they received freer vent. He compares the conditions which arise at such times to those occurring when the cork is removed from a bottle of charged water; if this be done suddenly a great proportion of the contents of the bottle is violently ejected, but if the cork is held back and the gas pressure allowed to pass off slowly none of the contents of the bottle are thrown out. In accordance with this theory the tendency in recent years has been to provide many less explosion doors than were formerly thought to be necessary, and the results have very largely confirmed the theory, though many furnacemen are not willing to go as far as advocated by Mr. Kennedy and do away with explosion doors entirely.

One design, made about the time of the Duquesne revolution, was intended to be the best possible regardless of expense. Some five or six outlets were provided around the top of the furnace and these were all connected with an annular main, from one or two points on which the branches of the downcomer led off. Explosion doors were arranged on the outside of this annular main, which, of course, was a few feet below the operating platform of the furnace top, and in order to provide access to it a supplementary platform was built a few feet below.

This system had almost all of the disadvantages which could be worked into one design. On the side opposite to the downcomer there was so little current of gas that the annular main became sufficiently choked up to make it virtually useless and one or two outlets on the side next to the downcomer carried off all the gas, practically as though the annular main did not exist. On account of the large size and distant location of the dust catcher and the wide stretch of its branches to reach the opposite sides of the annular gas main the slope of the downcomer was exceedingly flat and it is probable that after it was in operation a short time more than half its area was choked up and not in active use. One of the worst features of the design was the location of the explosion doors which, it will be seen, came just under the main operating platform. Owing to the choked condition of the downcomer the top pressure was high and the explosion doors were generally leaking more or less; if the gas caught fire it burnt underneath the top platform so as to damage the steel work, and if it escaped unburnt the gas came up onto the top platform in sufficient quantity to make it dangerous to stay there any considerable length of time.

It may not be amiss to say a word here as to the general design of explosion doors. These are always made hinged, but are located in two different ways; first, so that the plane of the door is horizontal

when closed; second, so that it is steeply inclined or vertical when closed. The latter design is radically wrong and should never be used because the moment of the door due to its weight is little or

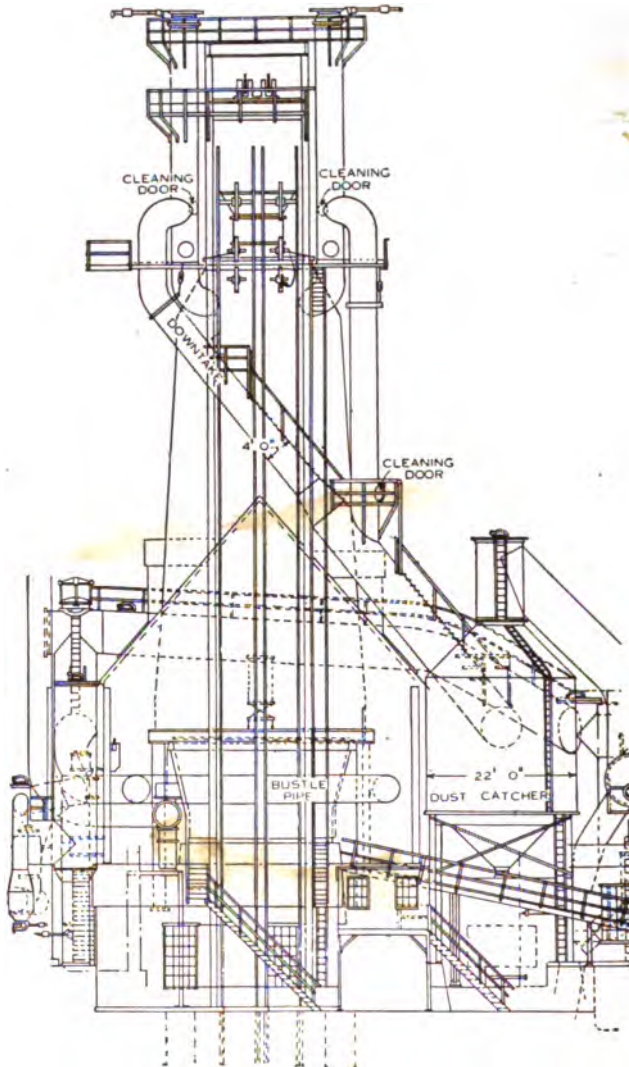


Fig. 178. Elevation of Bethlehem Steel Company's furnace showing correct design of gas outlets.

nothing when it hangs vertical, consequently a slight pressure is sufficient to force it from its seat, but as its moment rapidly increases a much greater pressure is required to force it to open wide, as it should when it is needed at all.

The horizontal door works exactly the opposite way, exerting its maximum moment when it is closed, so that it is very easy to keep tight under ordinary conditions, but when a considerable increase of pressure occurs, forcing the door open to relieve it, the moment of the door decreases as it opens so that it operates more and more easily as it opens wider. This seems at first sight to be an insignificant detail, but as a matter of fact I have seen great annoyances caused by vertical doors, so little gas leaking from them can be objectionable either by burning and damaging the structure or by polluting the air, that the final result is to have a rigid clamp put on the door which virtually destroys its usefulness for its primary purpose, even though it may not completely eliminate the leakage.

Fig. 178 shows a design of gas outlets and downcomer which secures practically all the important advantages. The drawing shows the "E" furnace of the Bethlehem Steel Company. The outlets are four in number rising from the conical top of the furnace shell. The downcomer instead of connecting directly with the outlet openings on the furnace shell on the back or high side connects with the outlet pipes at a point several feet above the operating platform and thereby secures sufficient height to give it a slope steep enough to free itself. The explosion doors are placed on the top of these high outlet pipes many feet above the operating platform and if they leak no harm is done. If the gas burns it cannot strike anything to destroy and if it remains unburnt it pollutes the air far above the heads of those who may have occasion to be upon the operating platform.

In the early days the downcomers were made of quite thin pipe entirely unlined and these gave remarkably good service considering the relatively high temperature of the gas they sometimes had to handle, temperatures of 800° or even 1000° Fahr. in regular operation being not uncommon, while, of course, very much higher ones occurred during slips.

In modern practice, however, the downcomer is always built of very substantial steel plate and lined with circle bricks from 3 to 4½ in. thick. This makes an almost indestructible construction but a very heavy one so that due care must be taken to support the weight of the downcomer at both ends. More than one case is on record in which no better support had been provided than the conical top of the dust catcher and this has buckled under the great weight thrown upon it.

Dust catchers. — Dust catchers were not considered a necessary part of a plant until within the last twenty or twenty-five years. The first ones were crudely designed, simply with the idea of providing an enlargement in the gas main in which the velocity of the gas would be reduced and its dust contents dropped to the bottom by this reduction in velocity. Ordinarily very inadequate means were provided to pre-

vent the gas current from again picking up the dust it had once deposited, and the efficiency of the apparatus was in some cases so low that the quantity of dust recovered was inappreciable, and after several

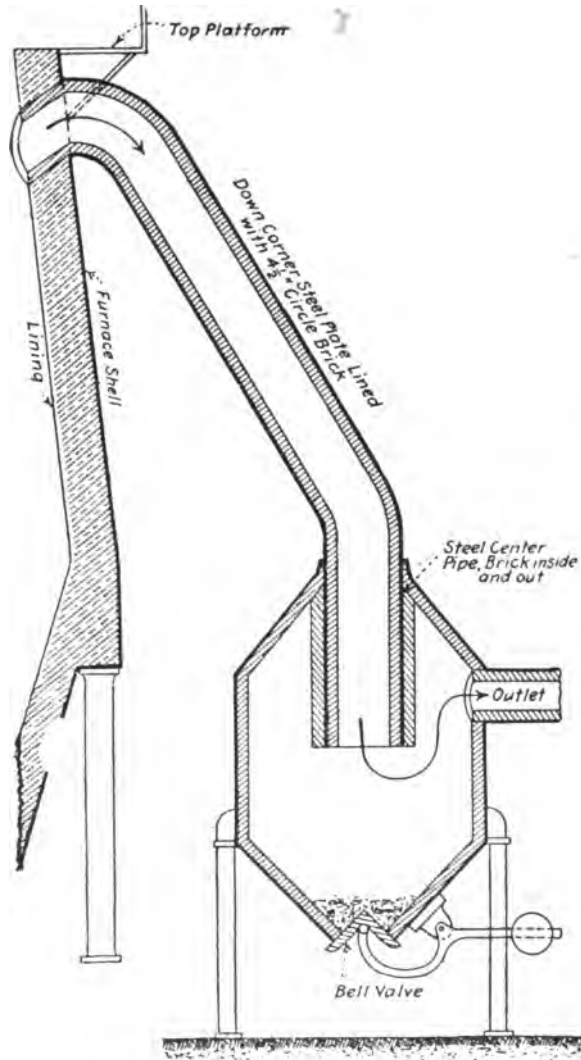


Fig. 179. Typical form of early dust catcher.

years trial the dust catcher was thrown out and replaced by a plain section of pipe. Eventually the idea took shape of combining centrifugal force with the reduction in velocity to throw out the dust.

The sketch, Fig. 179, illustrates diagrammatically the construction which came to be standard for the first type. Fig. 180 shows an early

type sometimes used to secure the centrifugal effect. The tangential inlet into the dust catcher body constitutes the principal difference in the two types, beyond the much steeper slope of the downcomer in Fig. 180.

The difficulty of preventing the dust from being picked up by the gas current after being once deposited was a serious one and its solution

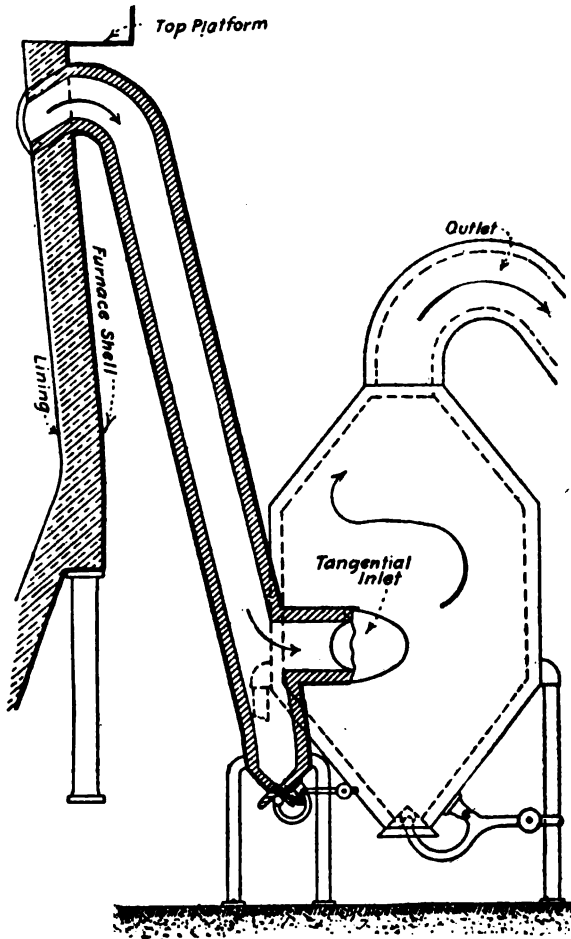


Fig. 180. Typical form of centrifugal dust catcher.

was sought by several furnacemen and several designs were brought out to overcome it by having the dust impinge upon the surface of water to which it would adhere and from which the gas could not pick it up again.

One of the earliest designs to embody this principle was that of Mr. F. E. Bachman, then manager of the Northern Iron Company, at Port Henry, N.Y. Mr. Bachman built a dust catcher in general

semi-circular passage repeats the operation once more and the gas is finally discharged at the far end of the dust catcher.

This design avoids the maintenance of the sprays required by the Bachman apparatus, but, on the other hand, the surface of the water is not constantly and rapidly renewed as it is in the Bachman design,

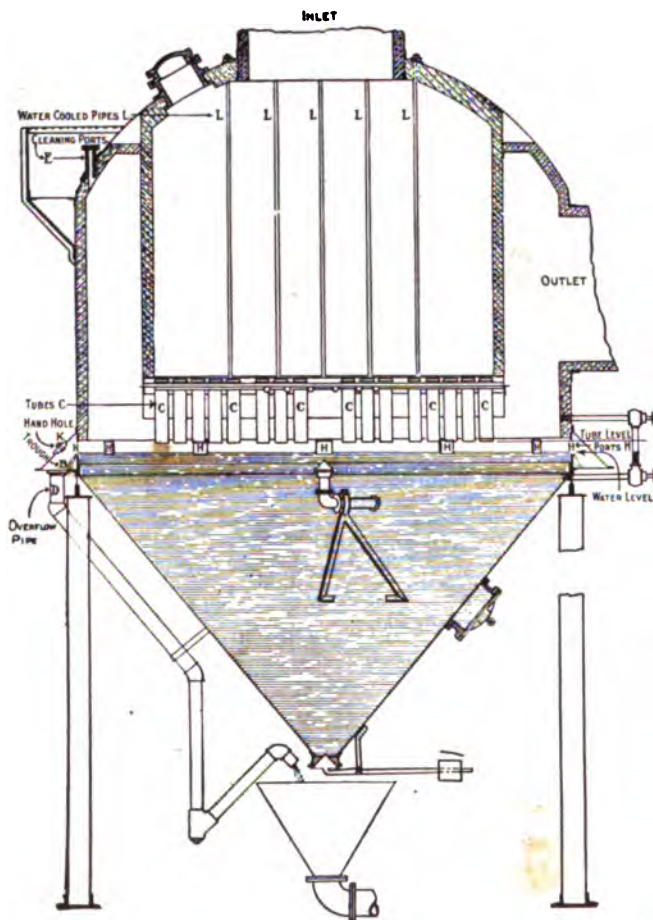


Fig. 182. Mullen gas washer.

and this is a point of much importance because when the surface of the water becomes fouled by a heavy layer of dust, other dust impinging upon this is not held but liable to be picked up again and carried on by the gas.

Another dust catcher which uses the principle of having the gas impinge upon the surface of water is the invention of Mr. B. F. Mullen, of Leetonia, Ohio. This dust catcher has had the widest application of any apparatus of its type. The design is shown in Fig. 182.

The external shape of the apparatus is not unlike that of the standard dust catcher. The gas enters at the top and passes into the central chamber shown. This chamber is suspended from the dome of the dust catcher, its shell is lined with firebrick and its bottom constitutes a tube plate supported by the suspension rods *L*. Through the tube plate project a great number of short tubes through which the gas is forced to pass at a considerable velocity. The bottom cone of the apparatus is filled with water to a level from 4 in. to 6 in. below the bottom of the tubes. This level is maintained by overflow through the ports *H* around the circumference of the dust catcher body.

Fresh water is introduced into the center through the pipe shown and flows regularly outward to the outlet ports *H* through which it discharges. This keeps the surface of the water constantly in motion and prevents its becoming too foul to hold the dirt thrown upon it.

After the gas leaves the tubes and impinges upon the water surface it passes into the annular space around the central chamber and so to the outlet at the side. The top of the water outlet trough just beneath the ports *H* is sealed by a conical plate the bottom of which is riveted to the bottom of the trough, while its top is riveted to the shell of the dust catcher proper.

The light dust which lodges on the surface of the water is carried away by the flow of the water, while the heavy dust which penetrates the surface is flushed off from time to time through the bell valve at the bottom of the cone. A later design is modified so that the outlet trough for the waste water is inside the main dust catcher structure instead of outside of it, but the principle remains the same.

This dust catcher has given very good satisfaction in use. The principal point to be guarded against is any fluctuation of the water level which will permit the end of the discharge nozzles to become wet, because if they do so the dust rapidly builds upon them and in time they become completely obstructed. A fact not generally recognized is that flue dust has a very cement-like quality and that when dampened it sets almost as hard as a good cement. This fact has proven the destruction of the number of wet dust catchers whose designers did not know how to provide against this difficulty.

Through the courtesy of the representative of the Mullen washer I have obtained a copy of the results of a test made on one of these washers by the superintendent of one of the largest blast-furnace plants in the country, with a view to finding out if the apparatus were suitable for the conditions at his plant. The results of this test showed that the gas leaving the dust catcher contained 2.28 grains per cubic foot of dust and after leaving the gas washer it contained 0.75. The representative of the gas washer claims that it is capable of doing considerably better work than this; even this reduced to a third the

total amount of dust carried in the stoves and boilers, and as a considerable proportion of the total is carried through by the stack gases without being deposited, the proportion which lodges in the stoves and boilers to their detriment is reduced in a considerably greater proportion. At the original plant where this washer was installed at Leetonia, Ohio, experience proved that they could run the stoves for the whole blast without taking them off the furnace for cleaning, which would be quite impossible without some means for reducing the dust in the gas far below the percentage which it contains on leaving the dry dust catcher.

Many other types of dust catchers have been built and tried out, but these described give the broad outlines of the art as it existed before the introduction of the gas engine. This forced a further step and a very long one in the direction of cleaning the gas, and as has so often happened, knowledge of the subject gained in learning to clean gas for gas engines has proven of great advantage in directions not contemplated when that work was undertaken. There seem to be definite limits to the degree to which the gas can be cleaned by any type of dust catcher which depends upon gravity, centrifugal force, or impact upon the water surface or combination of any of these. The degree of cleanness so obtainable is barely sufficient for moderately good practice with the stoves, and as has been previously explained, great economies were effected by cleaning the gas a step beyond this point for use with stoves.

Most of the processes used for the next step in cleaning have involved scrubbing the gas with water and this introduced another element in the situation. The gas as scrubbed picks up water vapor enough to saturate itself at the temperature at which it leaves the scrubber and this has a somewhat complicated effect. The gas as it comes from the furnace at a temperature of 300° to 500° carries a very considerable quantity of water vapor picked up from the stock which in a large proportion of modern practice is heavily sprayed with water just before being charged into the furnace. This water vapor is somewhat of a detriment to the gas since it acts as a dead weight during combustion and prevents attainment of as high a temperature as would be reached with the same gas at the same temperature, dry. By scrubbing the gas with water this temperature is reduced and its saturation point is so much lowered that water may actually be removed from it instead of being imparted by the scrubbing operation.

It is obvious that we have here two conflicting effects. The reduction of the temperature of the gas itself is bad because the sensible heat is an appreciable percentage of the total and if this is removed by any means, before the gas reaches the burners such removal represents an absolute loss. On the other hand, hot gas can carry an

enormous amount of water vapor and this moisture going through the system acts as a damper on the combustion and prevents the temperature from rising as high as it otherwise would. Therefore, to remove the moisture is in itself a benefit.

There has been a certain amount of misapprehension on this subject. There have been in recent months two papers on the subject of gas cleaning, of which jointly the value probably exceeds anything published in English previous to that time. These are the papers of Mr. W. A. Forbes, "The Cleaning of the Blast-Furnace Gas," before the October, 1913, meeting of the American Institute of Mining Engineers, and that of Mr. A. N. Diehl at the February, 1914, meeting of the same Institute, entitled "Data Pertaining to the Gas Cleaning at the Duquesne Blast-Furnaces."

From the former of these I shall presently quote extensively and from the latter also to a considerable extent, but both of these in my judgment give an erroneous idea as to the relative importance of removing moisture and of cooling the gas. Table 2 of Mr. Diehl's paper is reproduced here as Table 1 (see opposite page).

It will be seen that he gives calculations showing the amount of heat obtainable per cubic foot of gas under three conditions.

First — Washed and cooled to 70° Fahr. and saturated at that temperature with water vapor.

Second — Washed and cooled to 125° Fahr. and saturated at that temperature.

Third — Unwashed at 400° Fahr. and containing 35 grains of moisture per cubic foot; in other words, its natural condition as it comes from the furnace.

Three temperatures for the escaping products of combustion from the stack, 400° Fahr., 500° Fahr. and 600° Fahr., are taken for each of the three cases.

Turning now to the third line from the bottom, "Total heat obtained per pound of dry gas consumed," it will be seen that the amounts in the three cases, all at 500° stack temperature are 1076.6 B.t.u. for the first, 1088.43 for the second and 1166.49 for the third. It is obvious that the most available heat is to be obtained with hot gas in spite of high content of moisture.

Mr. Diehl gives percentage figures for the three cases in the second line from the bottom of 83.23 per cent., 78.4 per cent. and 80.31 per cent. Based on these percentages he states that the dry cold gas gives the highest percentage of available heat.

This is obviously incorrect, as the highest percentage must plainly on any correct basis of figuring coincide with the largest absolute amount of heat obtained. The error has arisen by counting as available the latent heat of vaporization of the water vapor in the gas in

TABLE I.—HEAT AVAILABLE PER POUND OF DRY BLAST-FURNACE GAS UNDER VARIOUS CONDITIONS OF INITIAL TEMPERATURE AND MOISTURE CONTENT.
COMBUSTION AIR CONSTANT CONDITIONS.

	Washed Blast-furnace Gas at 70° F. with Moisture Saturated at 70° F. Combustion Air at 70° F. with Moisture Saturated at 57° F.			Washed Blast-furnace Gas at 125° F. with Moisture Saturated at 125° F. Combustion Air at 70° F. with Moisture Saturated at 57° F.			Unwashed Blast-furnace Gas at 400° F. with 35 Grains Moisture per Cu. Ft. Gas at 62° F. and 50 in. Hg. Combustion Air at 70° F. Moisture Saturated 57° F.		
	Products of Combustion Cooled to 400° F.	Products of Combustion Cooled to 500° F.	Products of Combustion Cooled to 600° F.	Products of Combustion Cooled to 400° F.	Products of Combustion Cooled to 500° F.	Products of Combustion Cooled to 600° F.	Products of Combustion Cooled to 400° F.	Products of Combustion Cooled to 500° F.	Products of Combustion Cooled to 600° F.
Total Heat Expended Above 32° F. Fuel Gas.....									
Sensible heat in dry fuel gas, B.t.u.	9.128	9.128	9.128	22.449	22.449	22.449	99.61	99.61	99.61
Sensible and latent heat in moisture, B.t.u.	16.682	16.682	16.682	94.420	94.420	94.420	81.27	81.27	81.27
Latent heat of combustion, 1 lb. dry fuel gas, B.t.u.	1,253.800	1,253.800	1,253.800	1,253.800	1,253.800	1,253.800	1,253.800	1,253.800	1,253.800
Total, B.t.u.	1,279.610	1,279.610	1,279.610	1,380.669	1,380.669	1,380.669	1,434.68	1,434.68	1,434.68
Combustion Air:									
Sensible heat in dry air, B.t.u.	6.292	6.292	6.292	6.292	6.292	6.292	6.292	6.292	6.292
Sensible and latent heat in moisture, B.t.u.	7.729	7.729	7.729	7.729	7.729	7.729	7.729	7.729	7.729
Total, B.t.u.	14.021	14.021	14.021	14.021	14.021	14.021	14.021	14.021	14.021
Total heat expended, B.t.u.	1,293.630	1,293.630	1,293.630	1,394.69	1,394.69	1,394.69	1,448.70	1,448.70	1,448.70
Total Heat in Products of Combustion Above 32° F.									
Sensible heat in dry products of combustion, B.t.u.	144.65	144.65	144.65	144.65	144.65	144.65	144.65	144.65	144.65
Sensible and latent heat in moisture, B.t.u.	31.41	33.89	36.37	117.24	123.12	129.24	94.16	99.07	104.08
Total heat in products of combustion, B.t.u.	176.06	178.54	181.02	261.89	267.77	273.89	238.81	243.72	248.73
Heat Balance:									
Total heat expended, B.t.u.	1,293.630	1,293.630	1,293.630	1,394.69	1,394.69	1,394.69	1,448.70	1,448.70	1,448.70
Total heat lost in products of combustion, B.t.u.	176.06	178.54	181.02	261.89	267.77	273.89	238.81	243.72	248.73
Total heat available per lb. dry fuel gas consumed, B.t.u.	1,117.57	1,115.09	1,112.61	1,132.80	1,126.92	1,120.80	1,209.89	1,204.98	1,200.00
Total heat available per lb. dry fuel gas consumed, per cent.	86.39	86.39	86.39	81.22	81.22	81.22	83.52	83.52	83.52
Total heat dissipated in products of combustion, per cent.	13.61	13.61	13.61	18.78	18.78	18.78	16.48	16.48	16.48

all cases. But this is in fact not available under any known conditions of boiler or stove operation since it would require gases to be cooled far below 212° to precipitate much of this moisture and recover its latent heat.

It is obvious that if the unburnt gas comes in at 400° and goes out of the stack at 400° no loss whatever has occurred, while if it goes out at 500° or 600°, the only loss is that in superheating this small quantity of steam, 35 grains, or 0.005 lb., of water vapor, with a specific heat of 0.48 through a range of 100° or 200°, making a loss per cubic foot of gas of only a fraction of one thermal unit.

In regard to the effect on the temperature produced by combustion, the results are similar. The quantity of air required for combustion is about equal in weight to the gas itself, therefore the reduction of the initial temperature of the gas by a given amount results in a reduction of the combustion temperature by about one-half of that amount; to cool the gas from 400° Fahr. down to 70° therefore reduces the theoretical combustion temperature by about 160°. The removal of the moisture tends to raise the theoretical combustion temperature but quantitatively the amount of increase is smaller than the decrease due to the loss of sensible heat of the gas, about 100° against 160°.

When the gas comes from a furnace which does not work a wet burden of ore or wet fuel the conditions become very much worse for wet scrubbing, because in that case there is but little moisture in the gas to be removed by a reduction of the temperature and therefore such reduction represents a net loss both of temperature produced by combustion and of thermal efficiency due to lower combustion temperature.

In the discussion of the paper of Mr. Forbes above mentioned, it was stated by Mr. S. K. Varnes, of the Pennsylvania Steel Company, that at their furnaces they had introduced gas washers for the stoves but that they had been forced to abandon them because of the increased moisture and decreased temperature of the gas, which resulted in a decided lowering of the combustion temperature and corresponding reduction of the blast temperature that could be obtained from the stoves. On the other hand, great benefit has been derived from wet scrubbing, where wet ore is used. Thus it will be seen that each case must be handled on its merits. Clean gas is always desirable and undoubtedly much cleaner gas will be used in stoves and boilers than we have been accustomed to in the past, but wet scrubbing should only be adopted after the most careful analysis of the conditions to see whether the net results will be beneficial or not, and if so, to what extent. There is but little use in supplying stoves with clean gas and then finding that we can get from them only lower blast temperatures than we could with dirty gas.

With this introduction I cannot do better than quote extensively from Mr. Forbes' paper as follows:

"Dust content in gas. — The gas leaving the usual dust catcher contains an average of from 3 to 4 grains of dust per cubic foot, and its further cleaning is accomplished in one or two principal stages, depending on the ultimate use of the gas; namely, primary cleaning and final cleaning. In primary cleaning, the gas is sufficiently cleaned for economical use in heating hot-blast stoves and for raising steam in boilers; it has been found that the best results are obtained when the dust content of the gas, after cleaning, does not exceed 0.2 grain per cubic foot. In final cleaning, the gas is sufficiently cleaned for use in gas engines, and in this case the best practice has resulted when the dust content of the gas, after cleaning, does not exceed 0.008 grain per cubic foot.

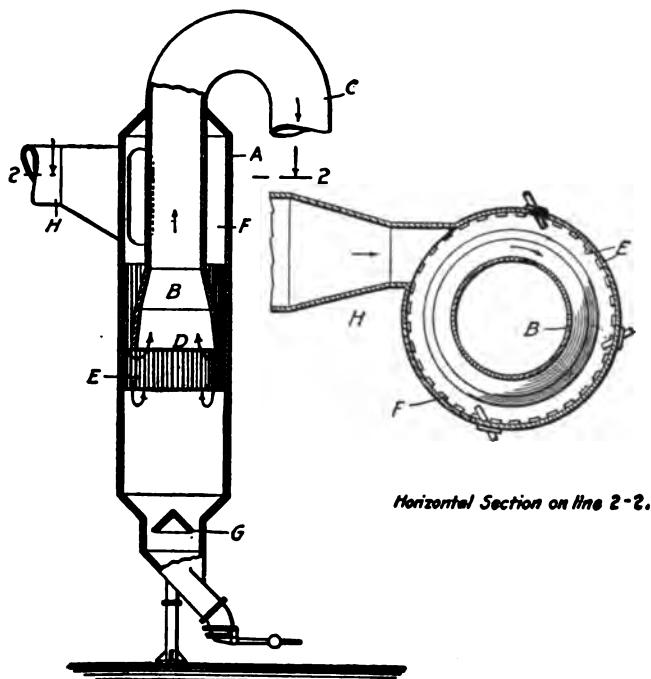
Various systems and methods are employed for accomplishing the desired results. In modern practice, the gas leaving the blast furnace is, in practically all cases, conducted through downcomer mains and then through a dust catcher of large capacity, and in some cases through two such dust catchers in series. A considerable proportion of the heavier dust is deposited at this stage. From the dust catcher the gas passes to the additional cleaning apparatus through gas mains, usually equipped with downtakes and valves for the removal of the deposited dust. The mode of treatment from this point on varies considerably, according to the opinions of the operators as to the respective merits of various systems.

"Primary dry cleaning. — For primary cleaning, a separation of the dust without the use of water — in other words, dry cleaning — has been in favor at many plants on account of the ability to thus conserve the sensible heat of the gas, which is lost when water is used. The fact, however, should not be lost sight of that the benefit derived from the sensible heat of the dry-cleaned gas is largely discounted by the amount of water vapor in the gas. This is especially the case with gas from blast-furnaces operating with a high top temperature and using ores and coke containing much moisture existing either free or chemically combined; the water vapor affects the efficiency of the combustion of the gas.

"An additional benefit of dry cleaning lies in the greater facility to recover and handle the flue dust in the dry state than in the form of mud or slime in the wet-cleaning processes. As before stated, the basic principles in practically all of these dry-cleaning systems depend upon a change in the direction of the gas, a reduction in its velocity, and the separation of the dust by gravity and centrifugal force. The various modifications by which this separation of dust is accomplished are all evolved from the so-called cyclone processes developed in Germany about 20 years ago. Some of these systems recently developed in the United States are the Brassert-Witting, the Roberts, the Kennedy, and the Dyblie. A description of the Brassert-Witting whirler and of the Dyblie whirler will illustrate the general principles of this type of cleaner.

"Brassert-Witting whirler. — As shown in Figs. 183 and 184, the Brassert-Witting whirler consists of a vertical outer cylindrical casing, *A*, and an inner inverted tube, *B*, which at its upper end is integral with the gas main *C*, which takes the cleaned gas away from the apparatus. This inverted tube is flared

at its lower end, *D*; a number of iron or steel bars, *E*, are fastened vertically around the chamber *F* and extend from a point well above the lower edge of the flared end *D* of the pipe to a point well below the lower edge of this pipe. In the lower part of the chamber *F* is placed a cone, *G*, which allows the separated dust to enter the outlet pipe.



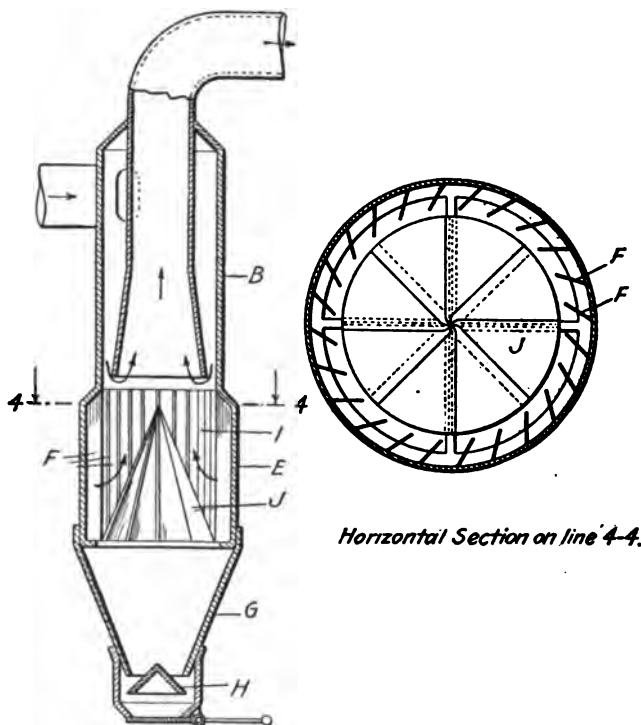
Figs. 183, 184. Vertical and horizontal sections of Brassert-Witting whirler.

"The gas enters the apparatus tangentially through the flue *H* and is given a rotary whirling motion through the annular space between the pipe *B* and the wall of the chamber *A*. On coming in contact with the bars *E* the dust is caught in the channels between these bars and is held in position by the combined action of centrifugal force and friction. As the gas continues to rotate within the annular spaces above mentioned, its velocity is gradually increased by the action of the flared end of the receiving pipe until when it reaches the lower edge of the end its velocity is at a maximum. On passing below this edge, the velocity is constantly decreased, the direction of the gas is changed and it passes upwardly through the flared end of the pipe to the outgoing gas main *C*.

"The dust which has been caught in the channels between the baffle bars drops vertically into the bottom of the chamber, past the cone *G* and into the outlet pipe, whence it is removed as desired.

"*Brassert modifications of Brassert-Witting whirler.* — In the Brassert modifications of the Brassert-Witting whirler, a sketch of which is shown in Fig. 185, the lower portion of *E* of the casing is larger in diameter than the upper portion *B* and is provided with a series of inwardly projecting baffle plates, *F*. The

lower portion *G* of the casing *E* is cone-shaped and constitutes the dust-receiving chamber. In the bottom of this chamber is a cone, *H*, whose function is to direct the dust toward the periphery of the dust outlet pipe. Within the chamber *I* another cone, *J*, is located and this cone is provided with a series of baffles, which are arranged as shown in Fig. 186.



Figs. 185, 186. Vertical and horizontal sections of Brassert modification of Brassert-Witting whirler.

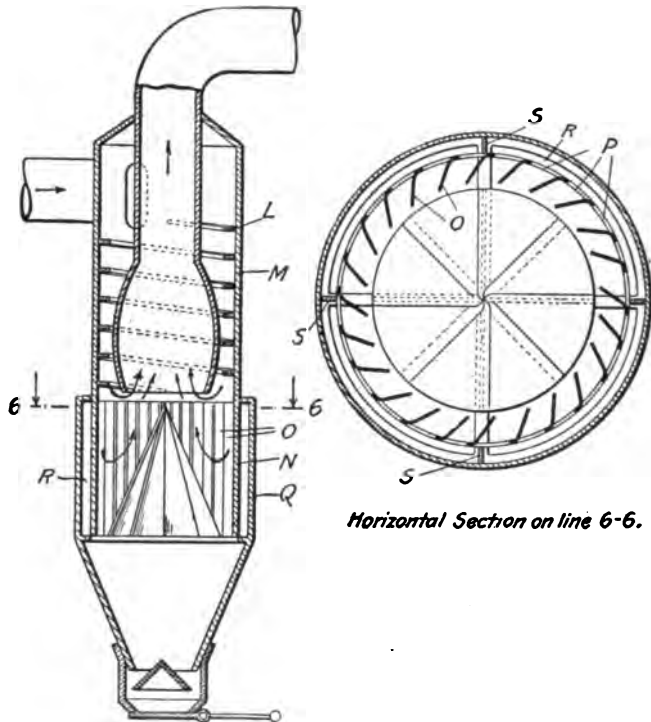
"In Fig. 187, which is a further modification, a spiral, *L*, is provided for the purpose of directing the flow of the gas. The lower end of the outlet pipe is made barrel-shaped. The outer casing *M* in its lower portion *N* is supplied with the baffles *O*, which instead of being mounted on the casing are bent inwardly therefrom, thus forming the apertures *P* (Fig. 188). The section *N* of the casing is inclosed by an outer casing, *Q*, thus forming the annular chamber *R*, in which partitions *S* are placed to prevent whirling of the gas in this annular chamber.

"The gas is introduced and discharged and the dust is separated in a similar manner to that mentioned in the description of the Brassert-Witting whirler.

"*Dyblie whirler*. — In this whirler, as in most of these types, the separation is accomplished by combined centrifugal force and the action of gravity. One of the principal features in this particular whirler is the arrangement in the spiral separator of the entrance and exit openings in substantially the same

horizontal plane, obviating the necessity of the gas changing its direction of flow at a sharp angle.

"Described in general terms, this separator consists of a spiral conduit, the lower open edges of which connect with the dust-collecting chamber. The gas is introduced tangentially and follows a spiral course toward the central axis of the apparatus, the spiral conduit being increased in area before the gas enters the central chamber, prior to its exit from the apparatus.



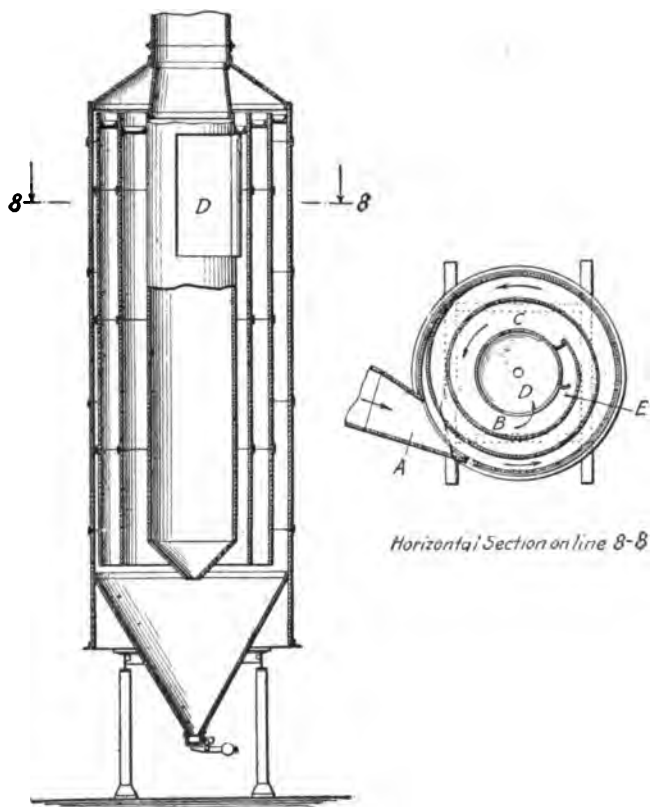
Figs. 187, 188. Vertical and horizontal sections of Brassert modification of Brassert-Witting whirler.

"The dust is separated from the gas by centrifugal force and gravity, and falls through the lower open edges of the spiral into the dust-collecting chamber. The central chamber is provided with a small opening at its lower end, and connects with the innermost spiral of the spiral conduit.

"In the accompanying sketches, Fig. 189 is a vertical section through the Dyblie whirler and Fig. 190 is a horizontal section. The gas enters tangentially from the gas main through the opening *A* in the shell of the casing; the gas impinges upon the first turn of the spiral *B* and follows the turns of the spiral. A separation of dust from the gas occurs through centrifugal force, the particles of greatest specific gravity being thrown outwardly and falling by gravity to the bottom of the casing. At the point *C*, an increased area is provided between the spiral and the central chamber, which causes a decrease in the velocity of the gas, thus allowing a further separation.

"The inlet *A* and the outlet *D* are in substantially the same horizontal plane, and this permits the separated material to drop out of the whirling gas and prevents its being caught up in the vortex, which happens when a sudden change in the direction of the flow of the gas occurs.

"A deflector, *E*, located at one edge of the opening, is provided. This is in the shape of a hook, which acts to catch any dust which might be carried into the casing, and this completes the separating operation.



Figs. 189, 190. Dyblie whirler.

Remarks on efficiency of dry cleaning. — It has been demonstrated in practice that dry cleaning by any one of the systems so far referred to, cannot be depended upon by itself to continuously clean the gas from blast-furnaces using much fine ore, to the degree desired for use in stoves and under boilers, the amount of dust remaining in the gas ranging from 1 to 3 grains per cubic foot, depending on the working of the blast furnace. Such systems have a value, however, in removing, by simple apparatus and at practically no operating expense, a certain proportion of the dust and so decreasing the duty upon any apparatus installed for further cleaning.

"The above remarks on dry cleaning refer in no way to the Halberger-

Beth system, recently developed in Germany, which will be treated separately later on.

"Primary wet cleaning. — For primary cleaning, in Europe in particular, a separation of the dust by the use of water has been preferred for many years to a dry separation, on account of the very much greater efficiency obtained in cleaning, and on account of the importance of reducing the water-vapor contents of the gas to a minimum, thus allowing more efficient combustion. The cooling and washing of the gas are usually performed simultaneously, sufficient water being used to reduce the temperature of the outgoing gases to practically the temperature of the incoming wash water. Experience has shown that cooling the gas in this manner, to allow condensation and separation of the water vapor, causes less attendant loss of heating efficiency than prevails in heating with vapor-laden gas.

"Zschocke system. — Zschocke washers have been used almost entirely in Germany for wet primary cleaning. These consist of cylindrical or square steel towers fitted with a series of wooden grids or hurdles placed at suitable intervals within the apparatus. These hurdles are arranged in such a manner that the water, which is sprayed in at the top of the tower, is broken up into very fine streams, which drip down between the grids and meet the gas coming up, the gas being introduced at the bottom of the tower. The intimate contact so obtained wets down the dust, which is carried with the water to the bottom. These Zschocke towers are usually water-sealed and cone-shaped at the bottom, and the latest type has a siphon arrangement; in either case, the dust is readily removed from the bottom of the apparatus.

"Zschocke towers have been found sufficient to cool and clean the gas to the proper degree for use in hot-blast stoves, under boilers, and for similar purposes. A fan washer, into which water is introduced, is frequently used as an auxiliary to the Zschocke towers for primary cleaning, especially when the scrubbing capacity of the towers is small.

"A water separator, equipped with internal baffles, is usually located beyond the washer to allow separation of the entrained water.

"Zschocke washers are used considerably in the United States, and some additional systems have also been developed here for the wet separation of dust; for instance, the Duquesne spray tower and the Steinbart spray tower. The basic principle of these spray towers consists of the creation of a rain or spray by means of suitably arranged nozzles, and the gas is cleaned and cooled in passing through this spray.

"Duquesne spray tower. — The Duquesne tower consists of a shell about 80 ft. high by 12 ft. in diameter. As shown in Fig. 191, the tower contains five sets of double screens, the sets being spaced 6 ft. 10 in. apart. Under the first set of screens are distributed seven nozzles, the feed water for which is controlled by a valve outside the tower. Under the fifth set of screens, seven similar nozzles, also controlled by a valve outside the tower, are distributed, just above the range of the lower nozzles.

"The controlling valves have a revolving core which successively blocks off the openings to the different nozzles, thereby temporarily stopping the flow of water and creating an area of low pressure directly above the nozzle. When the core has passed, the flow of water resumes through this nozzle and sprays

the gas which has reached this point. The core is revolved electrically, at the rate of about 15 revolutions per minute, and a 5-h.p. motor is ample to operate four valves, which are sufficient for two towers.

"The screens, which are placed above the nozzles, break up the water into fine drops, permitting intimate contact of the gas and the water.

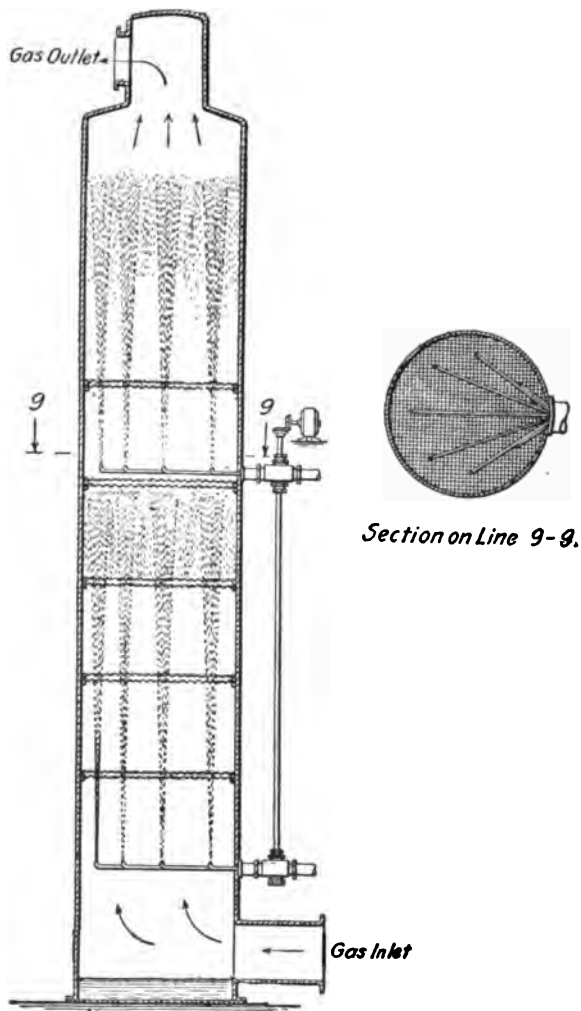
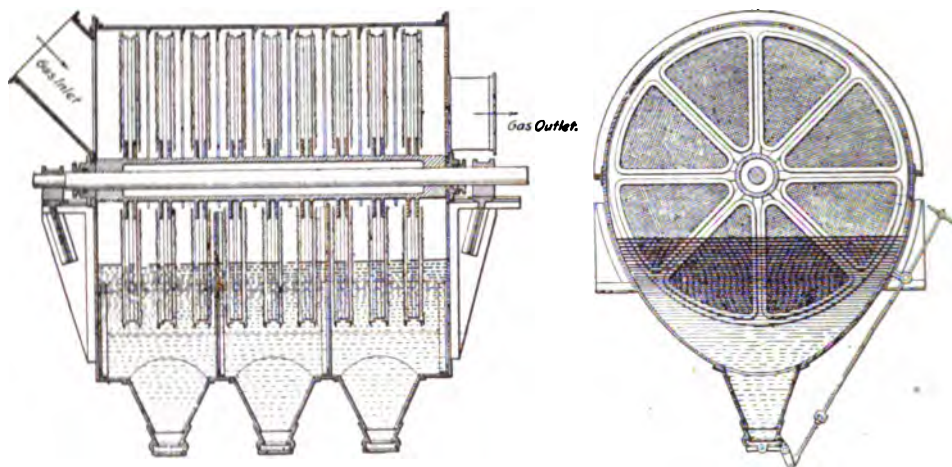


Fig. 191. Duquesne spray tower.

"In the operation of these towers at Duquesne, the gas rises through the scrubber at the rate of 4 ft. per second, and the water at the rate of 60 ft. per second with a head of 35 lb. main pressure. The gas is cooled down very effectively, the temperature of the outgoing gas being only from 5° to 6° Fahr. above the temperature of the incoming water, while the moisture content

averages only about 0.5 grain per cubic foot above the saturation point at the temperature of the outgoing gas.

Bian gas washer. — “The Bian gas washer, as shown in Figs. 192 and 193, consists of a stationary horizontal steel cylinder through which the gas passes from one end to the other. Inside the cylinder, there slowly revolves a shaft which carries a number of vertical disks consisting of wire netting of fine mesh. The diameter of these disks is very slightly less than the inside diameter of the



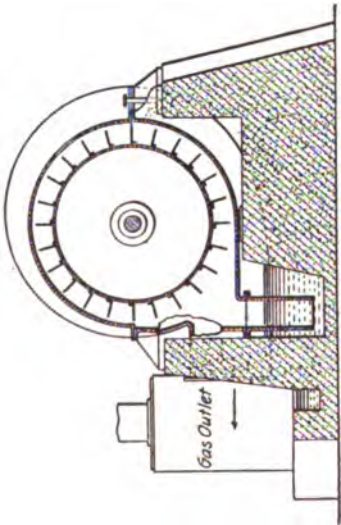
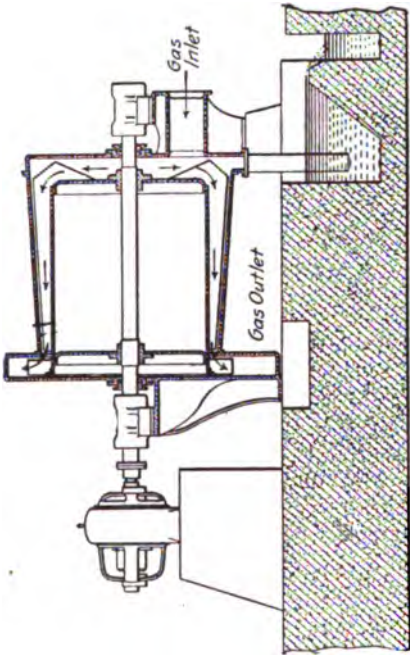
Figs. 192, 193. Bian gas washer.

cylinder, and this arrangement necessitates the gas passing through the openings in the screens as it travels through the apparatus. The screens, to the extent of nearly half their diameter, dip into water contained in a trough upon which the open bottom of the cylinder rests, and as the shaft revolves, the part of the screens which has been immersed rises from the water with the meshes covered with thin films of water, thus allowing thorough contact with the gas as it passes through the perforations.

“Final wet cleaning. — (Some of these systems can also be applied to primary cleaning.)

“The amount of cleaning accomplished in Zscheoke and similar towers, and in the Bian washer, while satisfactory for stoves and boilers, was found to be not sufficient when the gas was destined for use in gas engines, and the systems of Theisen and Schiele were developed for this purpose.

Theisen gas washer. — The Theisen washer, as shown in Figs. 194 and 195, consists of a casing lined with a special wire netting, within which revolves at a high speed, a drum carrying numerous fan blades set at oblique angles to the axis of rotation, these blades or vanes being so fitted that they form a continuous spiral curve. This allows the gas to be drawn in at one end of the casing and expelled at the other end. Water is admitted at the side of the casing and is converted into a fine spray by the revolutions of the blades, and the spiral arrangement of these blades causes the spray to flow in the opposite direction to



Figs. 194, 195. Theisen gas washer.

the gas, which passes through this spray, being simultaneously cleaned and cooled. The dirty water leaves the apparatus by a water seal at the bottom.

"The Theisen and Schiele systems of final wet cleaning have for years given very satisfactory results, but are now being gradually superseded by systems requiring less capital expenditure and less operating expense. Most of these systems can be used for primary cleaning as well as for final cleaning, by installing in two stages. The most important of the wet-cleaning systems which perform as efficient cleaning with the consumption of much less power and water than the Theisen and Schiele systems are the disintegrator system of Theisen, the disintegrator system of Schwarz-Bayer, the Fowler & Medley rotary washer, and the Feld rotary washer, while the Halberger-Beth dry-cleaning system of filtration through canvas is remarkably efficient in cleaning and is cheap to operate. Following is a detailed description of each of the systems mentioned, together with several other modern systems:

"*Theisen disintegrator gas washer.* — There are two styles of Theisen disintegrator gas washers. One style consists of a casing in which the gas enters by two apertures at the base of the apparatus and is washed by a spray of water in a perforated drum or cage equipped with vanes, the drum revolving within a stationary drum, the gas being drawn through the apparatus by a fan mounted on the same shaft and discharged with the necessary pressure to carry it to the point of consumption. The second style also has the fan mounted on the shaft, but the fan is inclosed within the disintegrator.

"The Theisen disintegrator consists of a series of rotary and stationary perforated drums or cages arranged concentrically within one another, as shown in Fig. 196. The stationary drums consist of round bars and the revolving ones of angle bars. The hot raw gas enters the apparatus at the bottom, meets the effluent water and undergoes a preliminary cooling and cleaning in the lower part of the machine. The gas is drawn in counter-current through the series of rotary and stationary drums by means of a fan. The water is converted into a fine spray by the centrifugal action of the rotating drums, and the gas, passing through this spray, is cleaned. The fan is located in the same casing and on the same shaft as the rotary disintegrating drums, the shaft being direct motor driven. Fresh water is introduced into the innermost rotating drums in the form of a finely divided spray.

"The cooling and cleaning of the gas and production of the pressure necessary to conduct the clean gas to its point of consumption are all performed in one apparatus and with one motor. It is stated that this disintegrator is an improvement over the former Theisen apparatus, requiring much less power and water, and performing the necessary cleaning of the gas without preliminary towers.

"*Schwarz-Bayer disintegrator gas washer.* — The Schwarz-Bayer system of gas cleaning makes use of the disintegrator principle, and its general arrangement is simple. The complete set of gas-cleaning apparatus consists of the disintegrator in connection with a saturating chamber in the form of a hood; then a fan placed immediately behind the disintegrator, and finally a water separator. In case both primary and final cleaning are desired, two such sets of apparatus are used, the second of which further cleans the gas which has been primarily cleaned in the first.

"The disintegrator, as shown in Figs. 197 and 198, consists substantially of

two sets of steel pins, cold-rieveted to two steel disks, which disks are set side by side and revolve in opposite directions. The pins of one revolving disk, which interlace with the pins of the other revolving disk, form with the water, through the effect of rotation and dripping, a fine spray or mist, which allows a thorough mixture of the water with the gas traveling among and between the pins before leaving the apparatus.

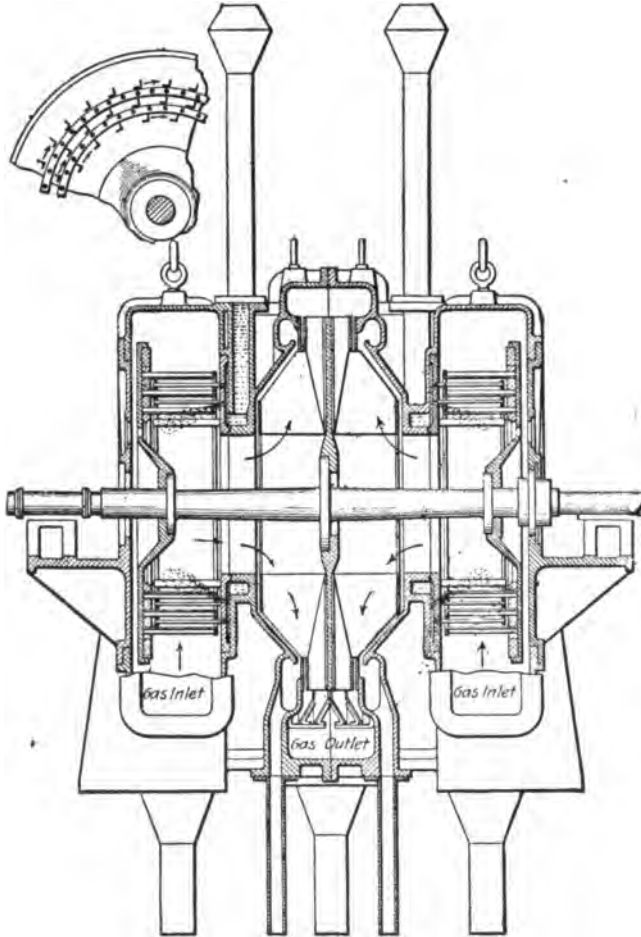
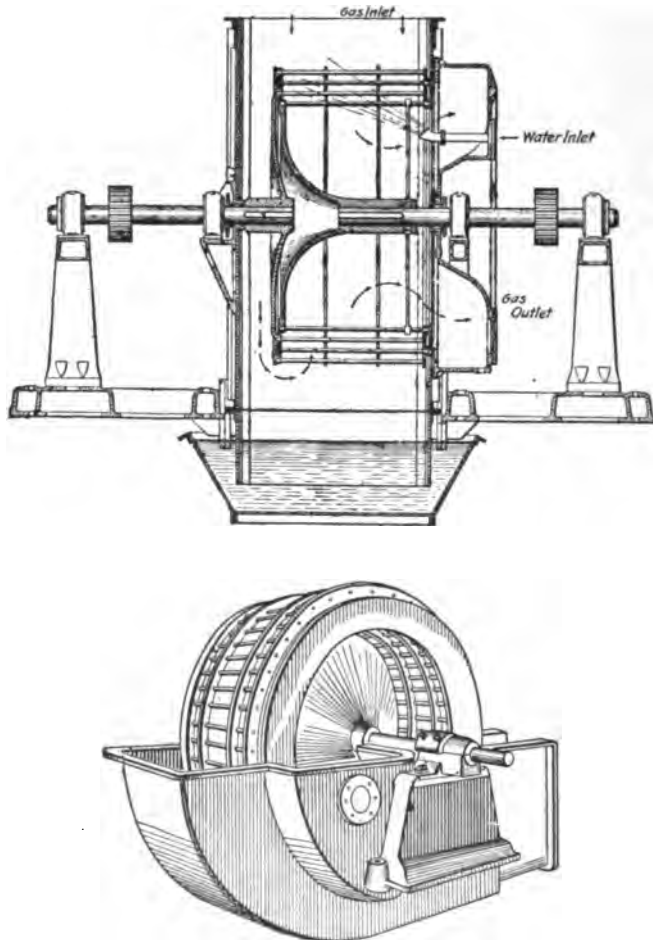


Fig. 196. Theisen disintegrator gas washer.

“The gases from the blast-furnace pass from the raw gas mains directly into the disintegrators without previously passing through Zschocke towers or similar preliminary washer or cooler. The gas enters through the top of the hood and passes toward the center of the disintegrator, while water is being introduced through the sides to the center. The hood acts to some extent as a pre-cleaner and cooler, as some of the spray from the disintegrators is thrown into the hood and there comes in contact with the hot gas and rapidly evap-

orates, simultaneously cooling the gas. By the revolution of the disintegrator the water is projected toward the periphery of the apparatus and is broken up into a fine spray; the gas mixes thoroughly with this water and is cooled, and most of the dust contained in the gas is precipitated. The gases pass through the disintegrator in a current counter to that of the water.



Figs. 197, 198. Schwarz-Bayer disintegrator gas washer.

“The application of the counter-current principle enables the gas to encounter cleaner and colder water in its passage through the disintegrator; hence it is better cleaned, and its temperature is reduced more nearly to the temperature of the entering cooling water. This principle has the effect of materially reducing the amount of water and power consumed. Each disk is direct driven by an individual motor and the speed is determined by the degree of cleanliness desired in the gas. The gas is drawn through the disintegrator by means of a

fan located immediately behind the disintegrator apparatus, and passes from the fan to a water separator.

"The use of pins in this apparatus as a disintegrating medium allows the passage of the gas with very little resistance, and a consequent saving in power. There is also very little possibility of the dust settling on the pins and clogging up the apparatus.

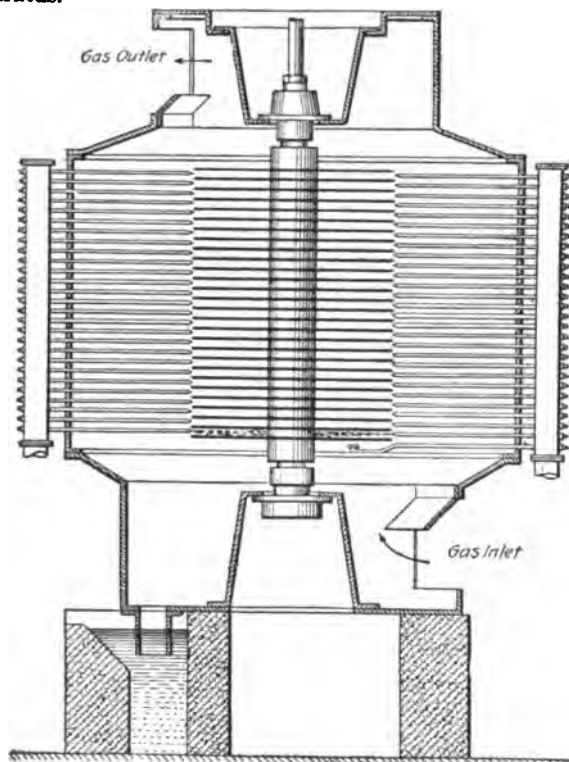


Fig. 199. Fowler & Medley vertical gas washer.

"*Fowler and Medley vertical gas washer.*— This apparatus, as shown in Fig. 199, consists of a circular cast-iron casing containing a revolving shaft running vertically through the middle. On this shaft are fixed a number of disks, made either of steel or of cast iron, depending upon whether the water used is alkaline or acid. Each disk is equipped with a collar separating it from the adjoining disks, and each collar is punched or drilled with six holes, through which six bolts pass vertically, thus holding all the disks in place. The shaft is direct driven with a vertical-spindle motor. Two fixed water sprays are provided for each disk, diametrically opposite each other, one on each side of the washer and projecting between each pair of disks. The jets of water, which are introduced through nozzles having about $\frac{1}{8}$ -in. openings, enter with sufficient pressure to strike the collar between the disks, and, as the disks revolve, the water is thrown against the top and bottom of these disks and then against the outside wall of the casing, creating a fine spray or mist in the space between

the outer edge of the disk and the wall of the casing, through which space the gas passes. The gas enters the washer at the bottom, passes through this spray or mist, and leaves clean at the top.

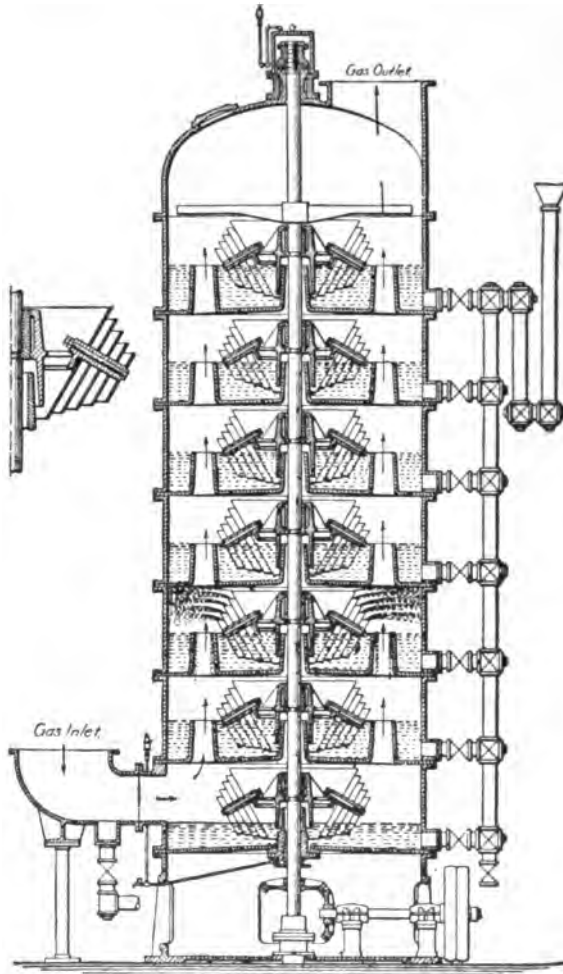


Fig. 200. Feld gas washer.

"This washer can be used for either primary cleaning or final cleaning, or both; in case final cleaning is desired, two washers would be used in series, the first apparatus to clean the gas sufficiently for primary purposes and the second apparatus to finish the cleaning of the gas for gas-engine use.

"*Feld gas washer.*— The Feld washer, as shown in Fig. 200, consists of a series of superimposed sections, the bottom of each section being provided with ports for the passage of gas. The gas enters the bottom of the washer and passes from chamber to chamber to the top, whence it is led away. Each section or chamber is provided with a series of cones perforated at the top and mounted

upon a cast-iron spider, which is carried on a vertical shaft. The shaft is suspended at the top in a specially designed anti-friction bearing, arranged so as to reduce the power required for operation to a minimum. The water is admitted into the top of the washer and overflows from section to section through the gas ports, the dirty water saturated with dust leaving the bottom of the washer.

"When the shaft revolves, the cones do likewise, and the water is raised by centrifugal force along the inner sides of the cones and is atomized at the upper edge. This upper edge of each cone is a little higher than the next outer one, thereby forming a certain number of horizontal sprays of water, depending on the number of cones. The upper portion of the outer cone, which is somewhat higher than the inner one, is perforated. The inner cones supply water to the perforated surface of the outer one. This results in the formation of a series of cascades composed of very small drops of water, through which the gas must pass en route through the apparatus.

"The washing is accomplished mostly in the lower sections, while the upper sections perform primarily the function of cooling the gas.

"For primary washing, the Feld washer is constructed with seven chambers or sections, the lower three being the washing chambers, the fourth one being a separating chamber and the upper three being the cooling chambers. For final washing, in the case of the gas being required for gas-engine purposes, the gas after being primarily cleaned is passed through an additional washer of the same general arrangement.

"*Reco centrifugal gas washer.* — This gas washer is constructed by the Roessing-Ernest Company, of Pittsburgh, Pa., and is designed to cool, clean and, if necessary, dry the gas in one apparatus. This washer consists substantially of a vertical outer casing, a tube whose lower end is provided with serrations extending to within a few inches of a water seal, a revolving inverted cup, and a sleeve casing attached to the inverted cup. The outer casing, the cup, the tube, and the sleeve casing are provided with shelves and vanes. The apparatus is belt-driven. The spindle of the rotor on which the driving pulley is fastened is hollow, and the weight of the rotor is taken up by the shaft inside of this sleeve held by a ball bearing which is backed by a rubber buffer in order to equalize any irregularity during rotation.

"As shown in Fig. 201, the hot gas enters the apparatus at the point *A*, passes over the water, a certain amount of which the gas takes up by evaporation, and then passes into the tube *B* through the serrations at its base. During its passage through this tube the gas and water vapor are subjected to a thorough beating and mixing by the action of the vanes *C* of the revolving sleeve casing *D*, fastened to the top of the inverted cup *E*. The gas passes into this inverted cup, which is rotated by the driving sleeve *F* and the pulley *G*, and then flows downward, around and under the lower edge of the cup and then upward between the cup and the outer casing *H*. The outer surface of the revolving cup is provided with concentric shelves *K* and the outer casing *H* is provided with downwardly inclined shelves *I*, which receive the washing water from the water-sealed stuffing box *J* and through a series of water pipes *L*. The water, falling on the rapidly rotating shelves of the cup, is thrown by centrifugal force against the inner walls of the casing and thence flows downwardly along the

inclined shelves, dripping on to the next rotating shelf, and so on. In this way the gas, while subjected to a thorough whirling and beating action, has to pass upward through several films of finely divided water or spray while the water passes downward, carrying with it the separated impurities.

"The apparatus operates on the counter-current principle, the cleanest gas passing from the apparatus meeting the cleanest water entering the apparatus.

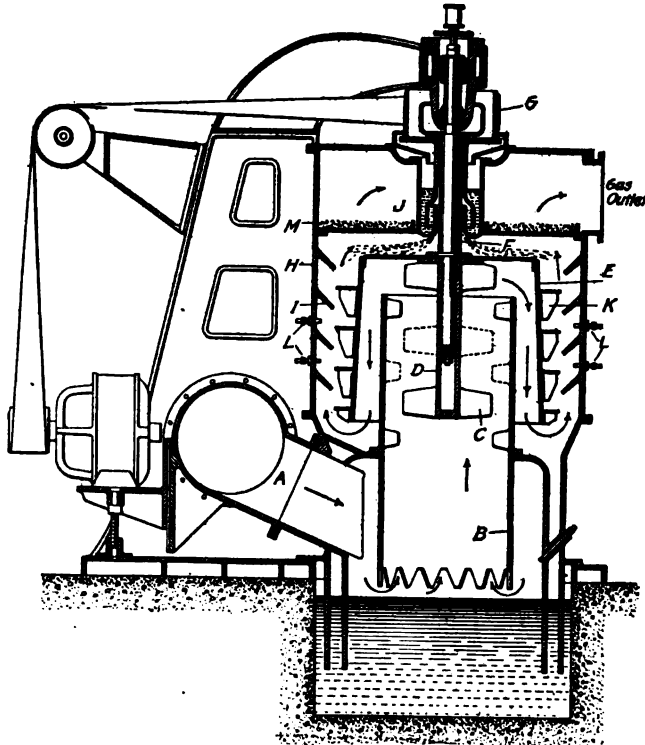


Fig. 201. Reco centrifugal gas washer.

"The upper part of the casing is provided with a rack which, it is stated, can be packed with suitable drying material in case it is desired to dry the gas before leaving the apparatus.

"*Sepulchre gas washer.* — This system is designed as a final washer to further clean primarily cleaned and cooled gas to the degree necessary for use in gas engines. The principle of this system consists in creating in a vertical tower a very fine spray or mist of water by means of an injector of the Körtling type, in which water under pressure is atomized by means of compressed blast-furnace gas, the spray being produced by the expansion of the compressed gas. An intimate mixture of the spray so formed, with the dirty gas entering the apparatus, is obtained by the arrangement of the apparatus.

"A separator is provided in connection with this apparatus, which consists substantially of a cone arranged in the lower part of the tower in such a way as

to leave between the base of the cone and the walls of the tower a very narrow passage, through which the gases are forced over the surface of a water seal, where the dust and water vapor are deposited.

"In the accompanying drawing, Fig. 202, *A* is the vertical tower, the lower end of which terminates a short distance above the surface of the water seal *D*. Within the lower end of the tower is arranged a conical deflector, *C*, and near the top of the tower is the gas inlet, *B*. The lower section of the tower *A* is surrounded by a casing which is open at the bottom and extends beneath the surface of the water in the seal. A gas outlet, *E*, is provided in connection with the outer casing. The Körtzing injector is located at *F* and the feed water for same is supplied through the pipe *G*. The pressure is supplied by withdrawing a portion of the purified gas from the outlet pipe *E* and forcing this by the compressor *K* through the pipe *H* into the injector simultaneously with a stream of water.

"*Final dry cleaning.* — (Some of the following systems can also be applied to primary cleaning.)

"*Halberger-Beth gas-cleaning system.* — The principle of the Halberger-Beth system, shown in Fig. 203, is based primarily on filtering the gas through canvas bags. The gas coming from the blast-furnace passes through the usual dust catchers and gas mains to a cooling tower, where the temperature of the gas is reduced to about 175° Fahr. The cooling tower is arranged so that the necessary amount of cooling can be accomplished either by air or by direct contact with water, depending on the temperature of the gas entering the cooler, which temperature is naturally variable, in accordance with blast-furnace conditions.

"From the cooler, the raw gas, by means of the suction of a fan placed beyond the filters, or without a fan when the pressure of the gas issuing from the furnace is sufficient, passes into and through the canvas filtering bags, depositing its impurities on the surface of the bags. These canvas filters are contained in a series of double compartments, each usually holding twelve canvas bags in rows of three by four. Each bag is about 8 in. in diameter by 9 ft. 9 in. long, and is equipped with a ring at each 18 in. of its length to prevent entire collapse of the bag when cleaning. The bags are fastened into a stationary header at the bottom, this bottom end being open, while the top is closed by a steel plate. Each bag is connected with a shaking mechanism located outside and above the filter compartment, and at regular intervals, usually about every four minutes, these bags are automatically shaken, a compartment at a time, for a period of from fifteen to twenty seconds. By means of a butterfly valve, the uncleaned gas is shut off from the compartment while the shaking is in progress, and cleaned gas, superheated to the proper temperature of about

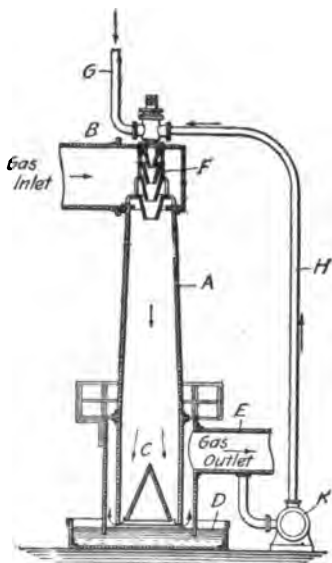


Fig. 202. Sepulchre gas washer.

175° Fahr., is forced under pressure into the compartment. This causes a partial collapse of the canvas bags, which, in conjunction with the simultaneous shaking, allows the dust to fall from the canvas. The separated dust drops into a hopper beneath the sacks, whence it is transferred by means of a spiral conveyor to a bin, from which it is loaded into cars. At the end of the cleaning period the butterfly valve automatically returns to its original position and filtering commences again.

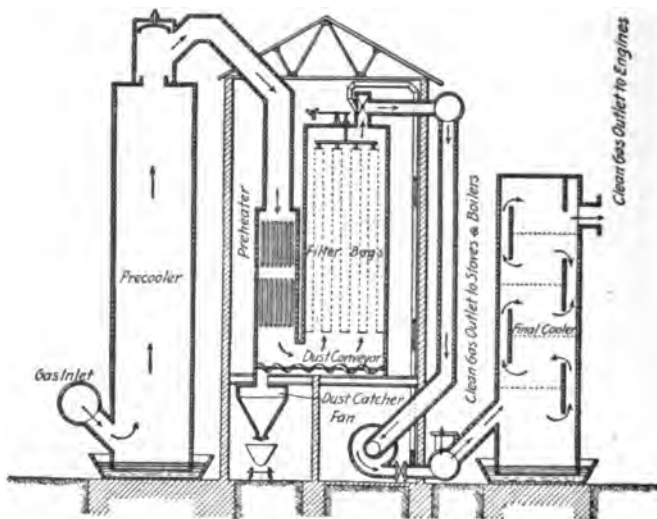


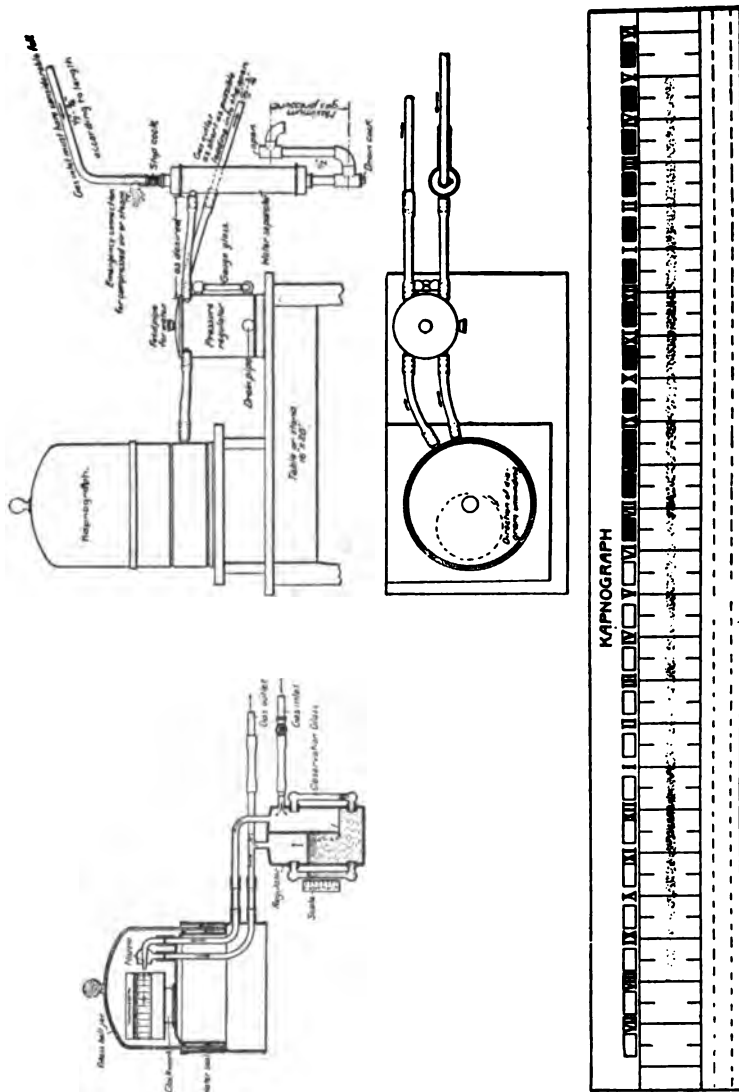
Fig. 203. Halberger-Beth gas-cleaning system.

"It is quite necessary to keep the temperature of the gas at about 175° Fahr., as if much higher than this there is danger of scorching the bag, while if lower the water vapor in the gas is deposited on the canvas and prevents proper filtration. In case the gas becomes cooled below 175° Fahr. in the cooling tower it is superheated by means of steam or by waste heat from the hot-blast stoves to about this temperature before entering the filtering bags. After leaving the canvas bags, the gas requires no further cleaning for gas engines and is cooled down to the proper temperature in cooling towers of various designs.

"The degree of cleanliness of the gas is indicated by the clearness of the effluent water from these towers and no settling basins are required. Consequently, this water can be used over and over again, which is a material item in districts where water is scarce. A further advantage lies in the non-pollution of streams, the laws relating to which are very strict in certain districts.

"This system utilizes the basic principle employed in the "bag house" system, which has been used for the last twenty years in connection with recovering zinc dust from the gas issuing from zinc-oxide furnaces and collecting dust from lead smelters.

"*The Kapnograph.* — This instrument, shown in Fig. 204, continuously indicates the relative degree of cleanliness of the blast-furnace gas going to the gas



Specimen of strip indicating one days run at a European Gas Engine Plant.

Fig. 204. The Kapnograph.

engines, and is extensively used in European gas-engine stations. Gas from the cleaned gas main passes through this apparatus and impings upon a continuous recording chart, upon which the dust and the gas is deposited. The variations in the amount of dust in the gas are indicated by lighter or darker shades on the recording paper, depending on the amount of dust deposited. The flow of gas to the instrument is maintained either by the natural pressure of the gas, or, if this is not sufficient, by an aspirator behind the outlet pipe. The speed of the gas to the nozzle is kept constant by means of a regulator, as shown in sketch, the excess gas over the required amount escaping into the outlet pipe by passing under a partition and through a seal of water.

"Methods of determining the amount of dust in blast-furnace gas. — A method employed with good results in Europe for determining the amount of dust in the gas consists in drawing a definite quantity of the blast-furnace gas to be tested through a filter, which is weighed in a dry condition before and after the test. The apparatus for determining the amount of dust consists of a glass tube drawn out at one end and fitted at the other with a ground-glass cover which is also drawn out to a thin tube. This cover facilitates the placing of the filtering material in the tube, and during the test the cover is fastened to the tube by means of wire. Before the test, the glass tube, filled with suitable filtering material, is placed in a drying furnace and heated at a temperature of 105° C. until its weight is constant, which usually requires from one to two hours. The drying furnace is arranged so that several tubes can be dried simultaneously.

"During the drying process air is drawn through the tubes after having previously been thoroughly dried by passing through bottles containing calcium chloride and concentrated sulphuric acid. During the drying process the tubes are weighed until no further decrease in weight is observed.

"In making the test, the weighed tube containing its filtering material is inserted into the gas main, a rubber stopper keeping the test-hole tight. The upper end of the tube is connected with a gas meter, which in turn is connected with a barrel filled with water. The water is allowed to flow out of the barrel and in so doing creates the necessary suction to draw the gas through the filtering tube and through the gas meter. When the necessary amount of gas has been withdrawn the tube is again dried and weighed. The increase in weight indicates the amount of dust in the quantity of gas tested.

"Brown dust, moisture, and volume determinator for blast-furnace and other gases. — This apparatus has been devised in order to determine accurately the amount of dust and moisture contained in blast-furnace gas, as well as the volume of the gas, and is used with considerable success.

Referring to the accompanying drawing, Fig. 205, *A* is a gas main conveying the gas to be tested. *B* is an aperture in the small pipe through which samples of the gas are drawn. *C* is a filtering medium within which the solid constituents of the gas are deposited. *D* is a conduit leading to the exterior of the gas main through which the filtered gas is conducted. *E* represents a flexible connection to a surface condenser, *F*. *G* represents a receptacle for some chemical, such as calcium chloride, which can be used for the purpose of taking out the moisture contained in the sample. *H* is a conduit from this moisture-removing receptacle to the rotary air pump, *I*, or through the by-pass *J* to the three-way valve *K* and thence to the gas meter *L*, where the volume of the sample is

determined, together with its temperature and pressure; these latter by means of the thermometer *M* and the U-tube *N*, respectively. An electric motor, *O*, is used to operate the pump *I* through the variable-speed drive *P*.

"An indication of the velocity of gas or gases in conduit *A* is transmitted through aperture *Q* in the sample pipe and conduit *R* to horizontal pressure gauge *S*; also an indication of the velocity of gas or gases after passing aperture *B* is transmitted from aperture *T* through conduit *U* to horizontal pressure gauge *S*. It is evident that changes of the velocity of the gas or gases in aperture *B* of sample pipe, produced by the suction of pump *I* or by pressure in gas main *A*, are indicated, and can be accurately controlled and made equal to the velocity of the gas or gases in conduit *A*, the gas main, such indicator being the oil piston shown in glass tube forming a part of the velocity gauge *S*.

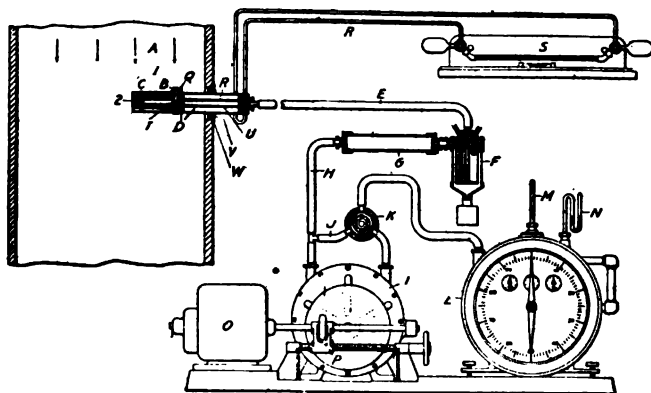


Fig. 205. The Brown dust, moisture and volume determinator.

"The method of operating this apparatus is as follows: The dry weights of the filtering medium *C*, of the receptacle *G*, containing the calcium chloride, and of the measuring flask attached to surface condenser *F*, are very carefully determined. They are then inserted in the apparatus, and the sample pipe is then inserted in the gas main, a tight connection being made between flange *W* and bushing *V*. The meter reading is noted. At the same time that the sample pipe is inserted in the gas main *A*, the time is noted, and the rotary pump *I* started. The speed is then so regulated that the oil piston in the horizontal pressure gauge *S* is maintained in equilibrium. This indicates that the velocity in aperture *B* is exactly equal to the velocity in gas main *A*, this condition having been determined by a measured amount of gas in gas main *A*, and the proper proportioning of aperture and conduits in the sample pipe during the calibration tests. This condition is maintained for an indefinite length of time and the sample pipe is then withdrawn from gas main *A*. The meter reading, multiplied by the ratio of area of aperture *B* to area of gas main *A* gives the total amount of gas passing through gas main *A* in the elapsed time. The difference between the dry weight of the filtering medium *C*, before and after the test, divided by the number of cubic units shown by the meter, gives the weight of dust per cubic unit. The moisture per cubic unit of gas is found in a similar manner from the sum of the weights of the water in drying receptacle

G, the water caught in the measuring flask attached to surface condenser F, and the weight of water retained in the filtering medium C."

Figs. 206 to 211 are reproduced from Mr. Diehl's paper as showing approved types of construction. The text of Mr. Diehl's concerns itself principally with operation and does not concern us here.



Fig. 206. Duquesne gas-cleaning plant, showing scrubbers, with intake from dirty-gas main and offtake to collecting main; also settling basins.

In addition to the processes so clearly described by Mr. Forbes, there are various others designed to remove the dust from the gas in the dry state, but as these have had no extensive application for the blast-furnace process, they may be omitted here.

Even since the time of Mr. Forbes' paper there has been an extensive development in Europe of the Halberger-Beth process of which there are now almost thirty plants in use in Europe and the number has been rapidly increasing. American furnacemen have been slow to take up this process and have acted in this matter along the same line as in many other cases; where an apparatus requires careful supervision or where its maintenance charges are high, operating economies secured by its use are disregarded. The same has been true in regard to the gas engine, by-product coke oven and many other kinds of apparatus.

This attitude is one often censured not only by foreigners, but also by Americans who do not consider all the aspects of such problems, particularly the financial one. The relative cheapness of capital and supervision and the costliness of raw materials in Europe as contrasted

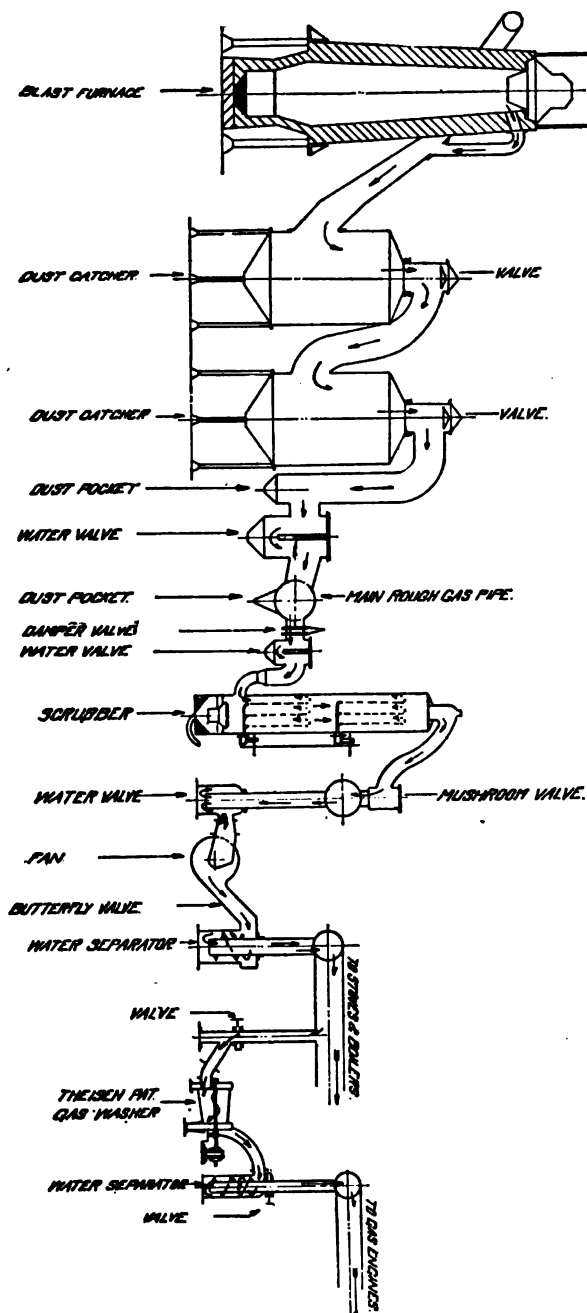


Fig. 207. The course of the gas through the cleaning processes to stoves, boilers and engines.

with the high cost of capital and supervision in America and the low cost of raw material constitute no small measure of justification for the American attitude.

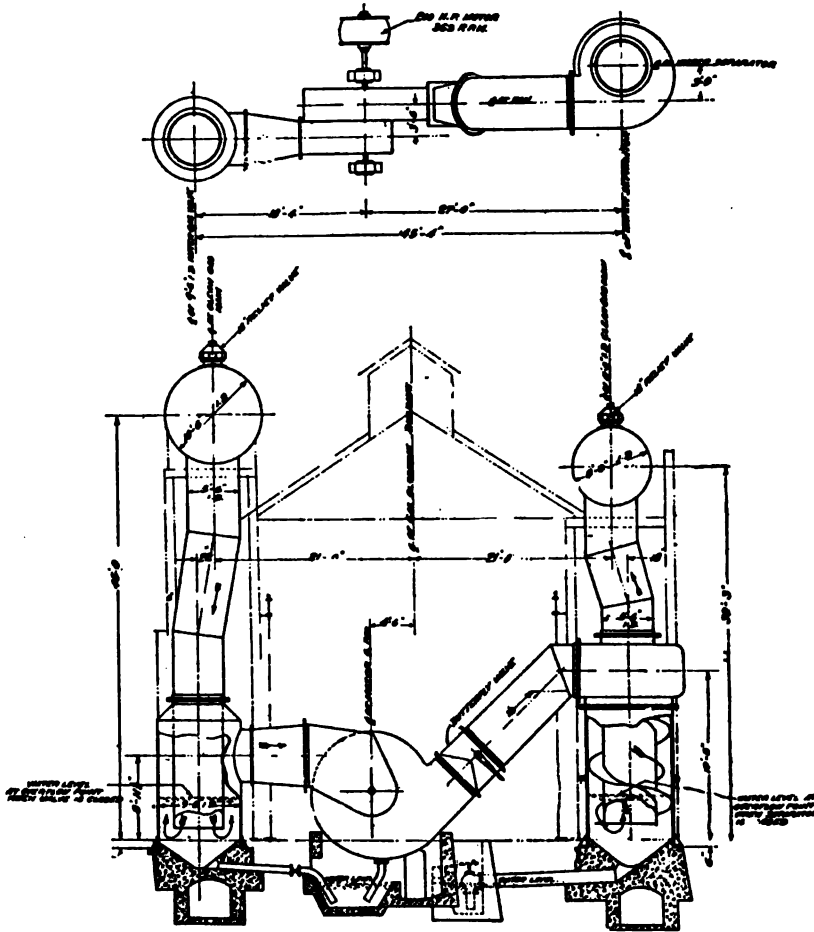


Fig. 209. Section through fans, and method of passing gas through seals and separators.

There is reason to hope that a process may soon be developed superior to either the wet processes or bag filtration plant and less complicated and difficult of maintenance. I refer to the Cottrell process for the electrical precipitation of the dust by a high-tension direct current passing through the gas column. This process has been developed to complete success in several lines of industry but its sponsors have hesitated to attack the blast-furnace problem on account of its size and the complexity of the conditions. If this process is ever worked out to a commercial success it will furnish gas absolutely clean with no loss of temperature and with no increase in its moisture.

These are the ideal conditions for the use of furnace gas for combustion purposes. For the gas engine it must in any event, in present practice, be cooled about to atmospheric temperature, and this, of course, can

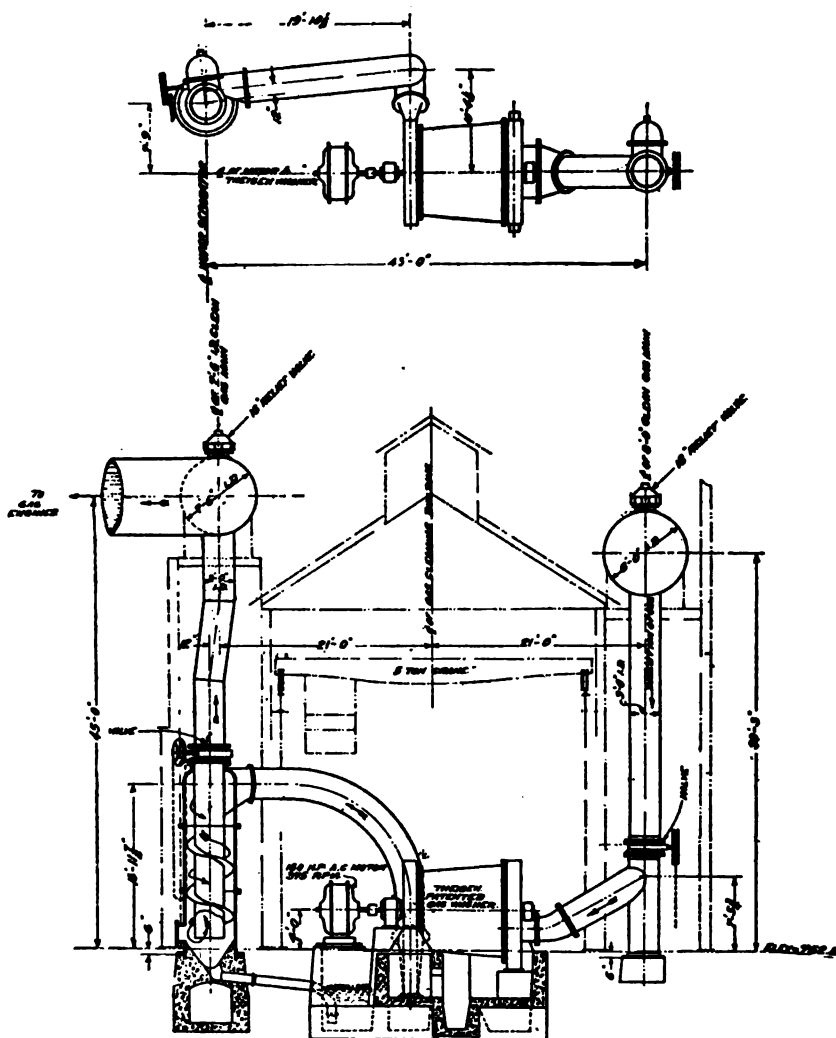


Fig. 210. Section through Theisens, seals and separators.

easily be done by a direct spray after the dust is removed. Perhaps the time might even come, if hot cleaned gas were available, that the gas engine could be adapted to its use and thereby further increase its economy.

In conclusion it may be said that it is impossible at the present time to write a history of gas cleaning. The whole development of gas

cleaning in this country covers barely twelve years in all and nine-tenths of it has been in the last seven or eight years. The advantages have become manifest and all furnacemen have sought *a* way rather than *the* way to clean the gas and undoubtedly they were right



Fig. 211. Dirty-gas main with clean-gas main at higher level, also the end of the refined-gas main leading from the Theisens to the engines.

in this course, for the plants installed early, even though not the last word of perfection in the subject, will have paid for themselves in bettered operating conditions before the much-to-be-desired best method is developed. It is possible, therefore, with this rapid development in progress, only to give an outline of the subject and to state briefly the principles which underlie its application.

CHAPTER VIII

HANDLING THE IRON AND CINDER

IN the early days of the blast-furnace it was probably the custom to allow the iron to run out in puddles in front of the furnace and there cool, but soon this crude practice developed into making a runner leading away from the furnace and putting short lateral runners off from one side of it so as to mold the iron into convenient shape for future handling. The runner was rather crudely formed as were the lateral runners, which were few in number.

The general appearance of the whole arrangement was roughly similar to that of a sow with a litter of suckling pigs. From this comes the name of "pig iron," while the runner from which the individual "pigs" are cast is known to this day as the "sow."

In still later times as outputs grew the pigs were not cast directly from the main central runner, but this branched into lateral runners at right angles to its course, and from these, at right angles again and therefore parallel to the main runner, ran the individual pigs. The combination of the branch runner or sow and the pigs which go with it are known as a "bed."

This system of casting the iron persisted as practically the only method of handling it until very recent years. Even at the time of the "Duquesne Revolution" when nearly everything else about the furnace was improved almost past recognition, the handling of the iron was changed in detail rather than in principle.

Casting in sand beds. — The runner and beds were until about twenty years ago practically always made up in sand, since sand does not wash in a liquid with a high surface tension like a molten metal, and at the same time is porous enough to permit the free escape of the gases generated by the action of the intense heat of the iron on the water and organic matter the sand contains. This is a matter of the utmost importance because if free escape be not permitted, when the pressure of the gases generated has risen to that corresponding to the depth of metal upon them, they bubble up through the liquid metal and this action is very vigorous because the head decreases as the gas rises, while the volume of the gas simultaneously increases as it bubbles up through the metal.

The consequence of these ebullitions is that the sand is disturbed when the gas is released, and the hot iron is given access to wetter and fresher sand underneath, with consequent generation of more gas and,

its release in turn, with a still greater tendency toward violence. This action continues progressively, if it once gets started, until a "boil" results.

These are spectacles of impressive beauty, like magnificent fireworks, for those not concerned in their results, but are frightfully expensive, not only in the loss of iron, but in the difficulty of removing that which remains in the center after the boil is over.

The depth to which one of these boils will dig in a short time is almost beyond belief, and if one occurs close to the front of the furnace so that there is no room to deflect the iron above it, it constitutes one of the worst interruptions that can befall the operation of the furnace.

I have seen a mass almost wholly of iron, but with a little cinder on top, about the shape of a huge strawberry, six feet in height and more in diameter, taken out after a boil at the end of the iron trough of only a few minutes duration. The difficulty of digging down to the bottom of such a boil and draining the liquid iron from the bottom of it is enormous, and a delay of hours in the operation of the furnace is practically certain to occur as a result of such a catastrophe in this location. For this reason the quality of the sand used in the pig beds, and particularly in the runner, is of vast importance. It must be coarse and open-grained, practically free from clay to prevent boils, and must also be free from lime, oxide of iron or any similar material which can unite with the silica at the high temperature of the iron and form a slag, since if such a slag be formed it causes great waste of sand, dirty iron and a tendency to make boils by sealing the pores of the sand beneath.

LATER DEVELOPMENTS

The first great change chronologically from this established method of handling the iron was the introduction of the mixer, of which, however, it will be more convenient to treat later.

Casting in chills. — Next to this came a change forced by the introduction of the basic open-hearth process for the manufacture of steel. In this all silica introduced into the open-hearth furnace has to be slagged with lime of something like twice its own amount, which it is very likely to seize from the bottom of the furnace, and so cause rapid wear of the latter, as well as heavy expense in the consumption of lime and fuel to melt the slag formed.

For this process, therefore, some substitute for sand casting was found to be almost a necessity; this was found in the use of chill molds. These are virtually pig beds of cast iron which replace the ordinary sand beds and are fed from the central sand runner, the same as the original sand bed. These chills are not a modern invention; I have seen one which was made, and presumably used, at a charcoal

furnace before the Civil War, but real need for sandless pig iron did not develop until the early nineties, and until then chills never came into general use because they are somewhat troublesome until the details of handling them are learned.

Certain irons, particularly hot irons, low in silicon, and made on a very limy furnace, have the power of attacking and melting away the surface of cold cast iron and so "burning" to it. Obviously if this action took place to any extent the pigs would burn fast in the chills, and it would be impossible to remove them. To prevent this the chills are washed with a solution of clay water soon after the removal of the cast from them, their heat then dries the water and leaves a coating of clay all over the molds. This is virtually infusible and serves to protect the chill from the action of the iron unless the latter is of an unusually cutting nature, when it sometimes burns fast to the chill in spite of the clay. Sometimes lime is used in place of clay, but clay is more easily held in suspension in water than lime, and is, therefore, more easy to apply uniformly.

These chills are exposed to enormous stresses. The whole bed of iron is obviously the same size as that of the chill at the instant of solidification, but as the iron cools off the chill absorbs its heat so that one gets hotter and the other colder. In order to get the cast out quickly it is customary to water it down with hose nozzles as soon as the iron has solidified, and this of course throws still greater stresses upon the chills, but if the molds in the chill which form the pigs are of the proper shape and properly reinforced, they stand up very well under this treatment. It is necessary to have a considerable thickness of metal below the bottom of the pig, six inches is a minimum and eight is considered better. The bars between the pigs are known as the "cores," and including these the average thickness of the chill is from nine to twelve inches. The width of the chill in the direction of the length of the pig is over four feet and its length may be anything dictated by the size of the cast house and local conditions, but beds eighteen or twenty feet long are not uncommon.

A brief calculation will show that these must be very heavy and in fact they weigh many tons. In some cases the beds are cast in two or three pieces, as this reduces the contraction strains and increases their durability; it also makes the individual pieces much easier to handle, although it is more troublesome to keep them in line with one another when made this way, unless longitudinal bolts are provided for holding them together, this is sometimes done and is good practice.

Breaking the Iron. — Each bed of iron when cast is obviously in the form of a huge comb and to render it merchantable this comb requires to be broken apart, and almost universally in foundry work the individual pigs require to be broken in two. This labor was in earlier

days performed exclusively by hand and still is in many cases. There are two ways of breaking, hot and cold; the former requires the less labor but is the hotter and the more disagreeable. It is done by catching the iron at the temperature immediately below solidification, when it still has very little strength, and breaking the pig from the sow by the use of a crowbar applied under the junction of the two. The men wear clogs with wooden soles an inch thick, kept soaked in water when not in use, which are strapped to their shoes. A good deal of dust arises from the disturbance of the sand, while the radiation from the pig beds is very great in spite of the fact that a thin layer of sand is sprinkled over them, which cuts the heat down very greatly.

In the South, where the conditions of atmospheric heat and humidity are relatively bad, the custom has arisen of allowing the men to break the iron cold. The beds are watered down as soon as they are cooled below the point where sudden chilling affects the fracture and appearance of the iron, the men then go on the beds with heavy sledges and crowbars and break the iron from the sow and break the individual pigs in two. This requires more labor and so is more expensive, but the work is more endurable for the men.

When the iron is cast in chills it is watered down and as soon as it has solidified the men work on it in pairs. One takes a short crowbar in each hand and pries up the point of the pig where its contraction has shortened it up so as to leave a gap of about half an inch between it and the chill. This man puts a heavy upward strain on this point with his hand bars, while his partner strikes a hard blow at the junction of the pig and the sow with an extra heavy sledge. This breaks the pig off from the sow and the latter is pried up and broken into two or three pieces by sledging, after the pigs are all broken from it.

Casting the iron into chills instead of casting it in sand exercises a profound influence on its structure, particularly with irons low in silicon such as are required for the basic open-hearth process and for which chills are used. If the iron be 1 per cent. or over in silicon its fracture is markedly different, when cast in chills, from that produced by casting in sand; it is much closer and finer grained, but the general nature of the iron is not much affected. But when the silicon gets down below 0.8 per cent., particularly if the sulphur be above 0.05 per cent., the iron begins to chill, and if the silicon drops still further it becomes perfectly white, very hard and excessively brittle. This is an advantage for steel-making purposes since it has been proven that chilled iron melts more easily than the same iron not chilled, and therefore this facilitates melting down the iron in the open-hearth furnace.

But for general foundry work iron cast in chills has only been introduced very slowly and after much missionary work among foundrymen who have very largely learned to judge the iron by its fracture

and general appearance, an iron of open grain with large crystals being in general much superior from the foundryman's point of view for general work to a close-grained iron with small crystals. Therefore casting in chills converted good iron into bad from the foundryman's point of view, and if the silicon was a trifle low, converted a really useful iron into one which foundrymen would not consent to use under any circumstances because it was "white."

This condition is gradually wearing away as foundrymen come to use analysis instead of fracture to judge the quality of their iron, but

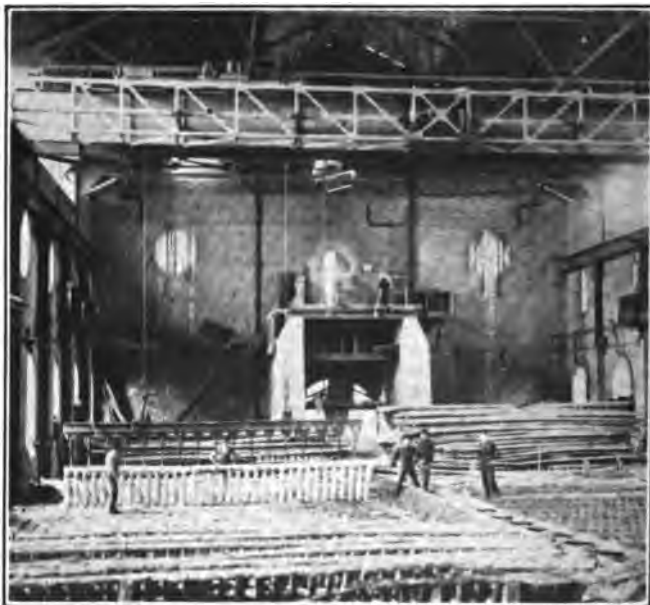


Fig. 212. Interior of cast house with pile of "combs" from pig beds. Crane lifting one pig bed out of sand.

many merchant furnaces supplying the foundry trade still continue to cast their iron in sand, and will for years to come.

Pig breaker. — The labor involved in these operations is generally not excessive measured in foot-pounds of work performed, but must be done in a relatively short time to permit the cast house to be cleared for the next cast, therefore the men have to do the work under high pressure and under excessively disagreeable conditions owing to the heat and dust.

In order to overcome these hindrances to continuous and inexpensive operation the Duquesne furnaces were provided with chill beds, but they were also provided with a crane in the cast house and the individual pigs were made vastly larger, both of heavier cross section and

much longer than the ordinary pig, and were picked up by the crane which carried them to what was probably the first mechanical pig breaker. There they were laid down upon a table of rollers which fed them up to a hydraulic plunger working up and down which broke them into short sections.

Since that time the introduction of the crane in the cast house has become more general and should be universal. It is not only an enormous saving of labor in handling the iron, as I shall presently show,

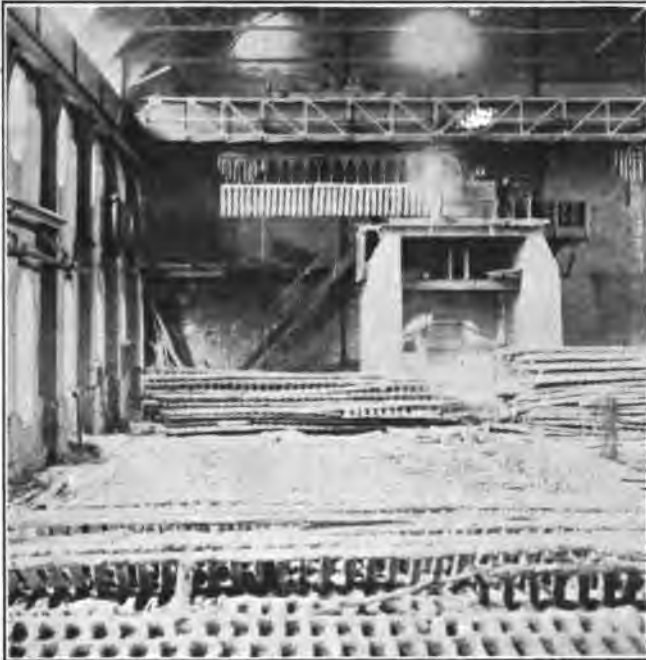


Fig. 213. Interior of cast house with pile of combs from pig beds, one hanging from crane.

but is a convenience of incalculable value in times of breakouts, boils, putting in and taking out iron troughs, and assisting in the operation generally.

Since the time of the Duquesne revolution the pig breaker has been much more highly developed, and in modern plants where pig beds are still used the handling of the iron is reduced to a mechanical operation.

The Brown Hoisting Machinery Company of Cleveland have developed the pig breaker in most common use, and through their courtesy I am able to show in Figs. 212, 213, 214, 215 and 216 the whole operation of handling the iron. In Fig. 212 there will be seen

suspended from the crane an I-beam carrying a number of heavy steel hooks. These hooks are lowered down over the bed and two or more of them are hooked under the sow and raise it on to blocks as shown in Fig. 213, in which position a fresh hold is taken of it with practically all the hooks engaged, the whole comb constituting a bed of two or three tons weight, may be either taken directly to the breaker in the rear or piled up as shown to the left of the breaker at the rear of the cast house. This is particularly convenient in case it is desired to have the analysis of the whole cast before breaking the iron and delivering it into the cars.

Fig. 213 shows the pig bed hanging from the hooks with its end entering the jaws of the breaker. It will be noted that the breaker



Fig. 214. Side view of pig breaker.

is set at a high level, and in the center between the two piers on which it rests may be seen a chute leading out of the arched doorway at the rear. Into this chute the pigs drop as they are broken and slide into the car which takes them to their destination. The iron therefore is practically never touched by hand in any way until it comes to be unloaded at its destination, and while that is no part of our present concern, it is not amiss to say that that operation is now very generally carried on by huge magnets operated by cranes, so that even there no hand labor is required.

Figs. 214, 215 and 216 show the pig breaker itself. The vertical column at the left, (Fig. 214) carries two horizontal plungers, one above the other, operated by hydraulic pressure. The column at the right acts merely as an anvil. In operation the comb is fed between the jaws by the crane; the first plunger is driven out against the top of the pig just where it joins the sow, and forces this over firmly against

the anvil. The lower plunger is then forced out against the projecting bottom end of the pig, which it breaks off across the horizontal fulcrum seen about midway of the height of the anvil. This breaks the pig in two, the sow being supported by its top edge, with the bottom edge unsupported, while the end of the remaining portion of the pig is supported on the fulcrum; more pressure is then thrown on the top plunger, which is opposite the unsupported bottom edge, and this additional pressure breaks the pig loose from the sow, and the sow is then broken into suitable lengths by proper manipulation of the position of the comb and of the pig breaker itself.

The hole in the floor just to the right of the operator (in Fig. 214) delivers the pig into the top of the chute shown in Fig. 213. There

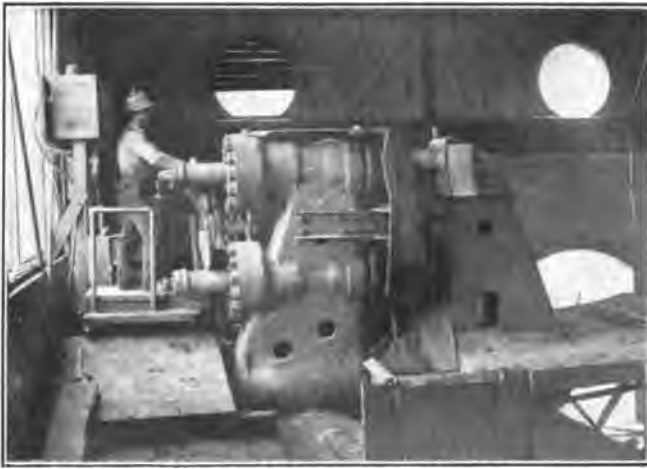


Fig. 215. Pig breaker, showing hydraulic cylinder and anvil.

is one of these on each side of the machine, so that no matter on which side the pig falls it reaches the same destination.

A pig machine has also been brought out by Mr. James B. Ladd of Philadelphia, but the principle of this machine, while somewhat different from that of the Brown, is not so radically different as to require separate illustration.

The amount of labor saved by the introduction of this equipment is enormous. When it is realized that 500 tons is considered the normal output of a standard size furnace in the Lake Ore district, and that under the old régime this would have required to be broken by hand, then carried piece by piece and thrown on to trucks, by them conveyed from the cast house to the railroad car, and then thrown from the trucks to the railroad car, it will be seen that the labor involved was tremendous and of the heaviest and most undesirable kind. Such

labor is increasingly difficult to secure, and to handle, and where pig iron must continue to be cast in sand, the introduction of methods of handling it by machinery is almost a necessity.

Molding up sand beds. — The beds were formerly molded exclusively by hand and still are in many cases. The sand is leveled off in the cast house floor, there is a pattern for the sow and one for each pig, which are set down on the level surface thus prepared, the sand shoveled off the bed to level it is thrown back between the pigs and tramped to place to pack it, then struck off the top of the pig patterns. These, which are made with a considerable taper, are then drawn by



Fig. 216. Part of pig bed or comb in jaw of pig breaker.

hand and thrown to the place for the next bed below, followed by the sow pattern.

This probably requires the most labor of any operation of importance around the blast-furnace, and no means have been found as yet to reduce it to a very great extent, although where there is a crane in the cast house the pattern for the whole bed is made up in one piece and handled by the crane; this saves a certain amount of manual labor, but so small a proportion of the total that the practice has in some cases been abandoned for the use of the old single patterns.

Various attempts have been made to reduce this labor but the sand has to be cut up with shovels after each cast has been watered down, not only in order to set in the pigs, but also because it is too

much compacted by the wetting to provide the necessary free vent for the gases. This, with the necessity of having the beds nearly level but with just enough fall to the sows and the pigs to cause the iron to run into them without overrunning the far ends, has made conditions too difficult to be met by machinery sufficiently simple and robust to perform the service in other particulars.

It seems not improbable now that the increasing use of the casting machine will eliminate sand casting entirely before mechanical methods are developed for molding the pig beds.

Handling liquid pig iron. — In the early days of the Bessemer process, the first applied to the manufacture of steel on a great scale, it was customary to cast the iron at the blast-furnace as described, take it to the steel works, melt it down into cupolas and then take it to the converters for conversion into steel. This was done so that an opportunity might be provided to analyze the iron and to make the mixture in the cupola suitable for use in the converters. This practice involved an enormous waste in two ways, first the labor of casting the iron into pigs as described above, and the handling of the pigs; second, the labor and fuel required for remelting these in the cupola. This was accompanied by a very objectionable increase in sulphur from the coke used in remelting.

Many metallurgists sought to eliminate this double loss by using the metal direct, but furnace practice was not as regular and uniform in that day as it is now, and there was no certainty that the iron produced at a given cast would be suitable for the converters because the last cast had been, and if the variation in composition were great the converter practice was completely upset.

The mixer. — The late Captain W. R. Jones, of the Edgar Thompson Works, solved the difficulty by the invention of the "mixer," a huge steel vessel lined with firebrick, mounted on trunnions and poured by tipping back and forth with a hydraulic cylinder. The first of these had a capacity of 150 or 200 tons of iron, but later ones have capacities up 600 and 800 tons.

All the iron from all the furnaces is poured into this mixer and that for all the converters is drawn from it. This provides a "cushion" to absorb the fluctuations in the quality of the metal and secures gradual variations of the metal delivered to the converter, which enables the converting mill to adapt itself to these changes without difficulty, while of course the mere fact of mixing the output of three or four furnaces necessarily reduces the average variation at least to one-third or one-fourth of that for any individual furnace, and generally much more. Thus the mixer exercises two good influences. It greatly reduces the absolute size of the variations, and it makes them gradual instead of sudden.

This improvement permitted the use of direct metal at the steel works, and practically all modern plants of combined blast-furnaces and steel works operate on this system. Where steel is made by the basic open-hearth process as well as by the Bessemer, a separate mixer is used for this iron, and the same advantages are secured in that practice.

Hot metal ladles — The use of "hot metal," as it is universally called, for the steel works involved the necessity of having ladle cars to transport it from the blast furnace to the mixer and thence to steel works. These started out quite small, ten or fifteen tons capacity,

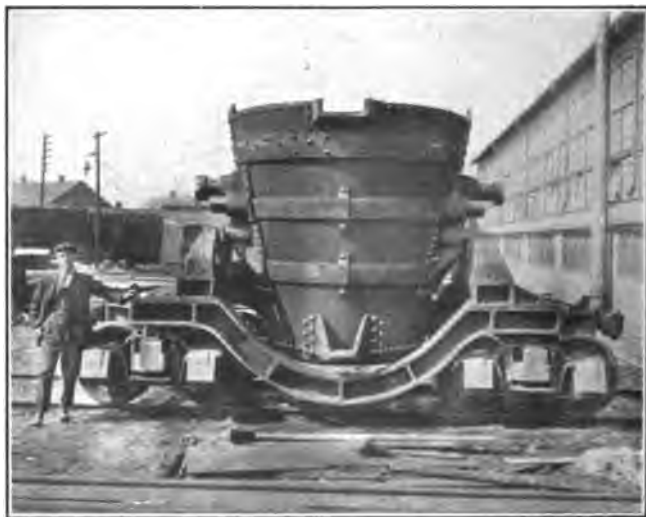


Fig. 217. Pollock hot-metal car.

but have gradually grown with the increased use of hot metal until 45, 50 and 60-ton ladles are now considered standard.

A ladle capable of carrying this amount of molten iron, some times for distances of several miles, with entire safety from breakage of the apparatus or liability to accidental tipping, and yet capable of being easily poured where desired, is an apparatus of no mean proportions.

Such a ladle built by the William B. Pollock Company is shown by Fig. 217. It will be noticed that this ladle is provided with five trunnions, two pairs below and a single one above on each side. It is also provided with a spout on each side and with a grip for a hook at the bottom immediately under the spout to provide a convenient hold for the tilting mechanism. The single trunnions above are used in carrying the ladle on cranes; the two lower sets are used for pouring from the frame of the ladle car itself. The ladle revolves during the early part of the tilting movement around the forward one of the bottom

pair of trunnions, but if it continued to revolve about this until empty its spout would be very low, necessitating a heavy drop for the metal poured at first in order to make room for the spout in its low position. The purpose of the upper pair of trunnions, with the corresponding jaws on the ladle truck shown beneath them, is to prevent this low drop of the ladle spout, and it is obvious that when these upper trunnions reach a seat in the corresponding jaws on the truck the ladle revolves around them, the lower pair leaving their seats. This obviously throws the spout up much higher at the conclusion of the pouring operation. By this means the drop from the spout of the ladle is reduced several feet over what it formerly was, which is an advantage wherever it is

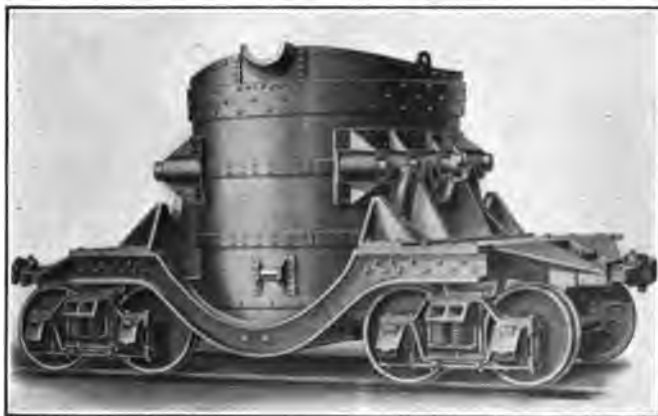


Fig. 218. Treadwell hot-metal car.

used, but particularly in connection with casting machines to be described presently. The receiving end of these with the old style ladle had to be placed below the track, but with the style here shown, on account of the high position of the spout at the end of the pour, these machines can be raised above the track with the result of making them much more accessible and less expensive to install.

A hot metal ladle built by the Treadwell Engineering Company is shown by Fig. 218.

Casting machines. — The increase of furnace outputs during the nineties, of which I have spoken, required very large cast houses to take care of the iron, and the labor involved in breaking and carrying out these huge quantities of iron by hand was, as I have already explained, frightful. The entire plant depended upon iron carriers, since the furnace could not be operated unless the iron were carried out, not *any* time but within a very limited period, so as to permit the beds to be made ready for the next cast. These conditions had the result of making this class of labor extremely hard to handle.

Conditions in this respect were, in one way, made worse by the growing use of hot metal at the steel plants, because it was necessary to have the iron carriers for Sundays and for emergencies when the steel works could not take the iron, while these men were not needed the rest of the time. This condition brought a demand for a mechanical means of taking care of the iron from the furnace. Casting machines had been in use at a much earlier period for copper, lead, etc., on a small scale, and under rather easy conditions, owing to the fact that the temperatures of those metals are far below the melting point of iron, so that iron-molds could be used without great difficulty.

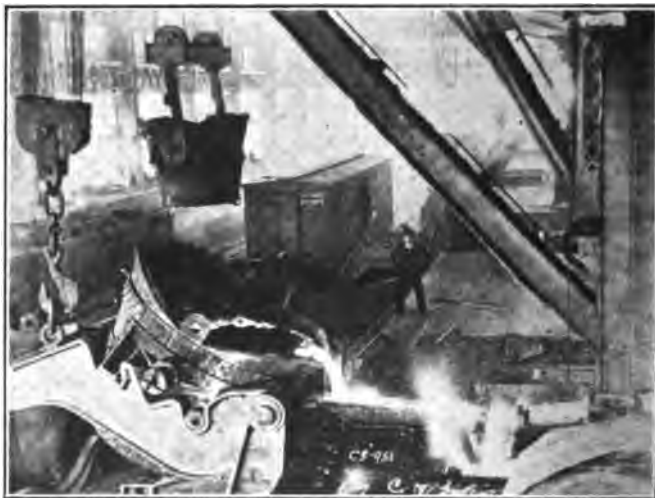


Fig. 219. Hot-metal ladle in pouring chain, pouring into branching trough which fills molds.

But the case was quite otherwise with the blast-furnace; the only material of construction available was iron or steel, and the iron cast into either of these was likely to burn fast to them if they were not thoroughly protected, while if the metal were poured into them while wet violent explosions would result.

Various engineers attacked this problem, but the credit for the first successful solution belongs to E. A. Uehling, who designed a machine consisting of two endless chains in tandem. The first carries molds for the pigs into which the iron is cast, it is chilled by passing under a heavy spray of water on its course, then discharges at the terminal sheave on to the second chain, a conveyor of slats running for some distance under water, which cools the iron down to a temperature low enough to do no harm, this conveyor in turn discharging on to the railroad cars which take the iron to its final destination.

Through the courtesy of the Heyl & Paterson Company I am able to show drawings, and an excellent set of photographs, of one of the largest installments of these machines ever built. Fig. 219 shows the ladle in a tipping chair which is elevated by the jib crane shown at



Fig. 220. First or casting chain of group of Uehling machines.

the right and pours into a trough at right angles to the track, which branches both ways at its far end, each branch pouring on to a separate strand of the pig machine.

Fig. 220 shows a general view of the ascending chain of the machine with the returning buckets on the under side.



Fig. 221. Group of Uehling type machines.

Fig. 221 shows clearly a general view of the machines, the head houses where the casting chains discharge on to the cooling conveyors, the terminal houses from which the latter discharge into the cars, and the excellent ladder arrangement of tracks for serving the machines

without the necessity of switching the cars under all of them to reach any desired car.

A view of the cooling conveyors with their water trough and the return side of the chain below is shown in Fig. 222.

The difficulty of having the metal burn on to the molds is obviated by having a jet of lime water from a tank underneath the return chain thoroughly sprayed up into the buckets as they pass over it on their return trip. The heat remaining in the mold causes the lime water to dry on it in a heavy white film, which of course is extremely refractory and prevents the contact of metal to metal, without which burning fast does not occur.

Another type of machine was brought out about the same time in which the functions of both chains are merged into one. This was the



Fig. 222. Cooling conveyors for Uehling type of machine.
Water troughs empty.

design of the Heyl & Paterson Company, who now build both the Uehling type of apparatus and their own.

In this apparatus one chain performs both functions. The metal is cast into it at one end, it then passes down a slight grade into a long tank standing full of water where the iron is thoroughly cooled, rises out of this tank at a sharp elevation and is discharged over the end sheaves directly into railroad cars.

A photograph of an installation of this type is shown at Fig. 223, also by the courtesy of the Heyl & Paterson Company. Unfortunately the machine was empty at the time the picture was taken, but the molds show so clearly, that their action is perfectly obvious, so is the way in which they pass under the water and out again and the overflow for keeping the water at the proper level. A photograph of the same apparatus before the water was turned into the tank is

shown in Fig. 224. The molds used in this conveyor are of steel, formed in the hydraulic press out of a piece of plate. They are subjected to terrific strains with the hot metal on one side of them and the cold water on the other, and after a certain amount of this service they lose their shape but can be repressed and restored to useful condition several times before they break from this treatment.

In some cases cast-iron molds are used instead of steel. These of course fail by cracking and not by bending and are not capable of any



Fig 223. Heyl & Paterson type of casting machine, steel mold, single chain, trough filled with water.

further use after such failure. On the other hand they can be melted up and recast direct from the furnace in the floor of the cast house with very small expense, whereas when the steel molds once fail the loss is greater.

Both styles of molds have their advocates and both continue to be used after a number of years experience so that the question of whether it pays better to use one kind or the other is probably very largely a local question.

The merchant blast-furnace isolated from steel works will probably prefer the cast-iron molds which it can produce from its own metal with a small amount of labor, while the steel works making steel plate and having available machinery for pressing the molds may find it cheaper to use the steel.

The introduction of casting machines of one type or the other has become practically universal at blast furnaces directly connected with

steel works, and even at many merchant furnaces. The huge cast house was one of the prominent features of the blast-furnace of former times, it has disappeared at modern plants and nothing is left of it except a building large enough to cover the troughs in which the iron is run to the spouts above the ladles and to serve as a protection against the weather around the base of the furnace itself.



Fig. 224. Heyl & Paterson type of casting machine, steel mold, single chain.

Iron trough and skimmer.—A violent explosion is caused by molten iron running on to even the smallest wet spot on anything made of iron, but it cannot bore into the iron as it does into the sand in case of a boil, so that the explosion, while violent and dangerous to the men, is limited to a single shot and the iron cannot work down to any depth as it can in the sand. A bad boil in sand at the tap-hole would prevent its being shut and would put the furnace out of commission for an almost indefinite time, constituting a catastrophe. For this reason a few feet of iron runner or trough has been used next to the tap-hole for many years. This is thoroughly grouted and carefully dried because the grout prevents the iron from burning to the trough which it would do if the latter were bare, while careful drying eliminates the danger of explosion.

Up to within a few years the runners from this point on were entirely of sand and the necessary arrangements for skimming the cinder from the iron were also built up of sand. The cinder has a specific gravity only about one-fourth to one-third that of the iron, and while the two come out of the tapping hole together during the

latter part of the cast, the cinder immediately rises to the surface and can be skimmed off without difficulty. To accomplish this the portion of the runner next to the iron trough is made very large relative to the portion below this section, and a dam of sand some six to twelve or more inches high is put into the bottom of it four to eight feet from the end of the iron trough; just above or in front of this dam is set a skimmer, formerly a thick plate of iron cast in open sand in the floor of the cast house, and guided by two pairs of pins driven into the sand of the runner on each side of it. When the cinder begins to show on the iron this skimmer is driven down with a hammer until its edge projects below the surface of the metal sufficiently to prevent the head of cinder floating on the iron from pushing under it, the cinder then rises and flows over a lateral dam, a low place in the side of the sand trough, and is led from there to its point of ultimate disposition.

With large and rapid streams of iron which were the consequence of the growing outputs of the nineties, this operation became more difficult and less certain. Either cinder was allowed to get down on to the iron, which created a fearful nuisance, as the cinder broke off when cold and fouled the pig beds, or the iron itself would be forced out over the cinder dam and wasted. Moreover there was left in the basin formed by the iron and cinder dams at the end of the cast a considerable volume of iron with a heavy layer of cinder on top of it. To direct this iron to its proper place and keep the cinder from following it was by no means an easy matter, and much iron was likely to be lost in the cinder without the most careful practice.

In order to overcome these difficulties Mr. Michael Killeen at the Edgar Thompson Works devised the Killeen skimmer. This consists of an additional section of iron trough linked to the section next the furnace. It has cast with it the cinder and iron dams, a slot in which to set the skimmer (preferably made of firebrick in an iron frame to prevent its cutting away during the cast, as the old iron skimmers did), and a supplementary lateral outlet extending clear to the bottom of the trough and closed by an iron gate with a staple in the top. Before cast this gate is set to place and the joint between it and the body of the skimmer trough well protected with sand and grout. With this arrangement the skimmer can project far enough below the surface of the iron to prevent the possibility of cinder getting down the iron runner, while at the same time the cinder dam can be raised so high as to prevent the iron from rising over it and running to waste. The considerable volume of iron remaining in the trough at the end of the cast is released by withdrawing the supplementary lateral gate and allowing the iron to run into a special runner which takes it either into a ladle or to a special bed set below the level of the other beds as may be preferred. The cinder is prevented from following it by a hand

gate dropped when the iron is all discharged and before much of the cinder can follow. This not only prevents the iron from being wasted and the cinder from getting down the iron runner, but also drains the iron trough effectively to the bottom so that easy access is thereby afforded to the tapping hole in order to stop it.

Other forms of skimmers have since been brought out, but are only variations of the general principle of the Killeen design.

Following the introduction of the iron skimming trough, iron runners were substituted for the sand runner all over the cast house. These are provided with grooves into which gates are set to cut off the flow of the metal, and are grouted after each cast with a mixture of sand and clay kept hot by a steam coil, the gate grooves being filled up flush with this mixture. With good practice only a very light skull of iron is left in these iron runners when the cast is over, and the runner requires only a new coating of sand and grout to make it ready for use again.

On account of its smoothness and uniformly sloping bottom the iron runner drains itself better than the sand runner, thus preventing the formation of any but light scrap; moreover, with the iron runner it is possible to raise a gate which has once been set and allow iron to flow again down a section of trough from which it had been cut off, which it is never safe to do with sand runners because the withdrawal of the gate from the sand is extremely likely to cause a boil. These advantages have resulted in the universal introduction of iron runners where the iron is run direct to the ladles and not cast in sand beds.

DISPOSING OF THE SLAG

In the early days of the blast-furnace the slag was handled as clinker or ashes, and this method of procedure survived until very recent times in the crane-operated shovel, fork, etc., which I have described in a previous chapter as adjuncts to charcoal furnaces in the seventies and which were used to clean out and "work down" the furnace very much as we find it necessary to do with the average domestic "heater" to-day. The difficulties of this method of operation, a growing knowledge of the use of flux, and the use of the hot blast with its correspondingly higher hearth temperatures, brought the possibility of discharging the slag in the liquid condition and this practice became general, though not universal, in the early part of the last half of the nineteenth century.

The slag was at first tapped out of the furnace with the iron, and after being skimmed off as previously described, was run off to a short distance into puddles in which it was allowed to cool. Slag being very brittle when cold is easily broken up by hand and was disposed of with carts or any convenient means, being simply loaded from the ground into the conveyance with shovels or forks. Carts dumped it into

holes or low places, and enough of these were commonly found near the plant to take care of the slag output of those days for many years. Survivals of this method are in use even down to the present time, though they have now become rather rare.

When mineral coal was substituted for charcoal as fuel, the quantity of slag produced per ton of iron increased to some extent, but probably not in the ratio which the volume of charcoal slag bears to the volume of coke slag to-day, because in the early days of mineral fuel much leaner slags were used, it being impossible to carry as much lime as we can use with the high blast heats obtainable to-day. Nevertheless the increase in slag volume was very considerable and helped to bring about a change in the method of handling slag. The introduction of mineral fuel led also to larger outputs per day and this in conjunction with the considerably larger production of slag per ton made the slag per day to be handled with mineral fuel a much more important factor than it was with charcoal, so that the importance of slag disposal grew even more rapidly than the question of handling the pig iron output, and a vast number of methods have been devised and practiced in trying to handle it with maximum economy.

A comprehensive search would be required to obtain a reasonably complete list of the methods which have been used on an industrial scale in the past, but as only a few of them have survived this is not needed, a description of a few of the most commonly used will suffice.

The first important development was the choice of a definite dumping place, chosen with the idea of affording room for slag disposal within a limited area for a long term of years and the provision of railroad transportation for delivering the slag to it.

Probably the earliest improvement was to run the cinder into long parallel runners roughly made up in coke breeze so that the size of the individual bodies of cinder is limited, because while this material is very brittle as compared with iron, the difficulty of breaking it up grows very greatly with the size of the body into which it is cast since, if it is cast into puddles of several feet across and a foot or two thick, it cools very slowly, and this slow cooling anneals and greatly toughens it.

When cast in long runners of approximately semi-circular shape, a foot across and six inches thick, it was handled with hooks, one in the hands of each of a pair of men, who broke the runner of cinder up into pieces three or four feet long, and swung these on to a pile by catching them with a hook near each end. The sections of runner were piled roughly together and allowed to cool still further, after which they were loaded on to cars and taken away. This cleared the beds for the next fall of cinder.

In other cases quite large holes, approximately round, were dug into the ground, the cinder allowed to run into these, and a bar or

hook of iron stuck into the center while it was still hot. After the cinder had hardened it was picked up by this hook, with the aid of a crane, and loaded for disposal. At the dump the cake was broken up and the hook or bar of iron recovered to be used again.

In other cases the cinder was cast into cakes on cars made entirely of iron, which had a perfectly flat top, so hinged to the body of the car that it could be tipped laterally in either direction. On top of these were set cast-iron frames, the section of a truncated pyramid with the sides sloping inward at the top, without top or bottom. A joint between these and the deck of the car was made with breeze or fine cinder, and they were run full of cinder direct from the cinder trough at the furnace. After cooling, the iron frames or molds were

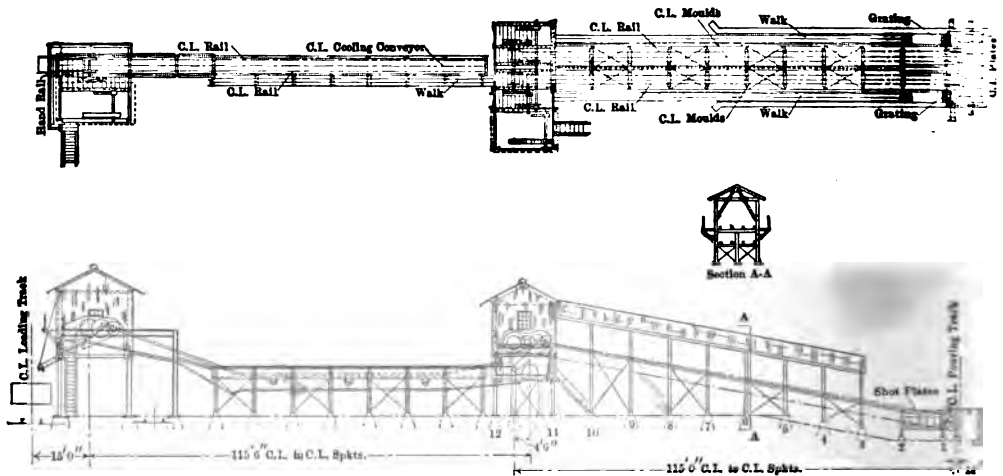


Fig. 225. General arrangement of Uehling casting machine.

lifted off with a crane, the train of cars taken to the cinder dump and the decks tipped, allowing the cakes to slide off over the dump. In this case of course, as with practically all dumps, the tracks must be moved either laterally or built ahead as the dumping space is used up.

About thirty years ago the practice of handling the slag in the liquid condition began to receive quite general recognition, and has developed continuously and rapidly from that time. The first liquid cinder cars were simply huge rectangular tanks of steel plate, lined with firebrick, mounted on trucks, with a spout on each side closed by a hinged gate. The gate was closed, a little cold cinder thrown against it, and the tank was then filled with liquid cinder and hauled away. At the dump the gate was swung aside and the cinder chilled over the opening broken through, the contents of the car then ran out. But this method was open to serious objection because even when very quickly handled, slag forms quite a heavy skull under such conditions,

and this skull fastening itself to the brickwork grows with each successive filling and emptying of the car until the capacity is so diminished that it must be cleaned out by hand, a laborious and time-consuming



Fig. 226. Pollock cinder ladle.

operation. If the car were allowed to stand until the cinder froze on top it made matters still worse as this additional skull also had eventually to be handled by hand.

To eliminate these difficulties cars which dumped their contents by tipping bodily over were developed. These also were at first made of



Fig. 227. Treadwell cinder ladle.

steel plate lined with firebrick, but even when emptied by tipping over they skulled up quite rapidly, and it was finally found that cast-iron pots could be successfully used, and that being smooth inside, the skull freed itself from them very much more readily than from the

brick. These at first were made of the same shape as the steel plate ones had been, with almost straight sides and flat bottom, which gives maximum capacity, but it was found that by increasing the taper of the sides the pots could be made not only to dump cleaner, but in the dumping position to throw out the skull without barring or hand cleaning. Consequently such pots are now universally made with a heavy taper and are almost cones, having only a small rounded bottom. The design of the William B. Pollock Company is shown by Fig. 226 and that of the Treadwell Engineering Company by Fig. 227.

Much ingenuity has been expended in devising the best mechanism for controlling the movement of these pots and dumping them with the least labor. After they had been in use for some years with the dumping gears driven entirely by hand, Mr. Samuel Stewart, then master mechanic of the Woodward Iron Company at Birmingham, Ala., patented a successful design in which a steam cylinder mounted on the car and connected to the locomotive supplied the power for dumping and restoring the pots to their normal position without any labor and in much less time than was required for the hand-operated pots. This idea has now been applied universally to these pots, but with the very general equipment of locomotives with compressed air for brakes, air is used to operate the cylinders instead of steam. With this device a whole train of these cars can be tipped, emptied, the skulls thrown out, and the cars restored to normal position, in a period measured only by seconds.

By the use of these side-dump pots the dump may be built up approximately to track level on the dumping side so that the tracks can be moved over with but little labor, when the drop from the cars is no longer sufficient to free them properly, but cars of this type do not permit dumps to be carried ahead except by the laborious method of building up the dump at the end of the track by hand filling.

In order to make room as fast as it is used up, it is generally very desirable to build a track ahead, and for this purpose other types of cars have been devised. The earliest of these was the design of the late John M. Hartman. It consists of a half cylinder of steel plate lined with firebrick, with an extension around the top of cast-iron plates, one side of the cylinder being flared out to make a pouring lip and the other side extended up vertically. This half cylinder rests on a four-wheeled truck, to which it is fastened by two pairs of chains, one with the front end fastened to the cylinder and the back end to the truck, the other with the back end fastened to the cylinder and the front end to the truck, one pair of these being on each side. These act practically like a rack and pinion and leave the cylinder free to roll on the truck without the possibility of being displaced endwise

by sliding; it is guided laterally by half rings of angles riveted to the cylindrical surface, which work between guides on the truck.

These cars are not coupled to the locomotive directly, but by means of a push pole sixteen to twenty feet long. After filling at the furnace these cars are taken to the end of the dump, the truck locked fast on the track with a powerful brake, or "scotched," the locking mechanism of the body released and the half cylinder pushed over by the locomotive operating through the push pole, which is fastened to the car with a swivel coupling.

The disadvantage of end-dump cars is of course that only one can be dumped at a trip, and if several have to be handled as many tracks must be provided as there are cars, or nearly so, because the heat at the end of the dump after dumping the car is too great to permit dumping another immediately, and of course a separate switching operation is required for each car dumped, in fact two of them when more than one ladle car is used, one switch to dump the car and set it out, another to pick it up and take it back.

It is a curious fact that these cars build a dump which is almost precipitous in its slope, both on its sides and on the front. A "fill" can be constructed from them with great economy of material because its sides are almost vertical.

On the other hand, the side-dump cars produce very flat slopes. As little as ten or fifteen degrees suffices to carry the slag away from the track with this type of car.

Another type of end-dump car with a round "thimble" like that of the side-dump car is made by the Treadwell Engineering Company and works with a similar mechanism, but fore and aft instead of laterally. It is of course a more difficult design because the truck is in the way of a free end-dump, but this difficulty has been successfully overcome.

Laying out the slag dump.—How a slag dump is to be handled is very largely a matter of local conditions, but I have always felt that the benefits of the end-dump car for building ahead were not properly appreciated, and that the ideal combination would be two or three, or even four or five side-dump pots with an end-dump pot on the front. With this arrangement all could be dumped simultaneously without switching, and the end-dump pot would build ahead about as fast as the side-dump pots used up the track room it provided.

The "hot pot" method of handling slag is economical for a large plant of furnaces, and where dumping room is available within a reasonable distance; but in congested districts where the only available land between high bluffs and a river is a narrow strip of bottom, every inch of which is necessary for plant and railroad tracks, it is not always easy to find a place in which to dispose of the slag without

a long chance that one will later on be exceedingly sorry for having put it there. Of course if a river or harbor can be filled to the harbor line this makes an ideal condition, but one which will not last indefinitely. Moreover, this method of handling slag requires a locomotive and crew in absolutely constant attendance day and night, Sundays and holidays. If the cinder cars get off the track, which not infrequently happens on the rough tracks on the dump, and the cinder train is blocked, the furnace may be put to desperate straits before the situation is relieved by the return of the cinder cars. The expense of the locomotive and crew is just as great for a single furnace as it is



Fig. 228. Brown hoist crane loading cinder from pit on to railroad cars.

for three or four, and the cost of slag disposal per ton of iron produced is therefore very much heavier by this method in small plants than in large ones.

Slag granulation. — These difficulties have prevented the universal adoption of this means of slag disposal, and have caused the development of others, of which by far the most important is "granulation." This was first practiced in this country, so far as known to me, by Captain T. C. Jones, at a small blast-furnace near Lynchburg, Va., and was subsequently applied by him, and is still continued in use, at a furnace at Iron Gate, Va., where the slag is flushed directly into the James River and carried away by the current of that stream.

The method consists in running the cinder out through a trough with a projecting end, just beneath which is placed a flat jet or nozzle about the same width as the trough. When the cinder starts to run

a powerful current of water is turned into this nozzle, and the cinder running from the end of the trough falls onto this jet whose velocity is sufficient to tear it into small shot as it runs, and these, of course, are prevented from recementing by the chilling action of the water.

Most plants which use this method of slag disposal are not so located that they can flush the cinder directly into a river, and these have installed huge concrete-lined pits or tanks, sunk in the ground, into which the cinder and water from the jet fall together, and from which the cinder is recovered, generally by means of a clam-shell bucket, and loaded on to cars. It is cold by that time so that there is no danger



Fig. 229. Brown hoist traveling crane and grab bucket for handling cinder.

of fire; the cinder is between coarse sand and fine gravel in size, generally rounded, and a very easy material to handle. It of course may be carried any distance desired to make fills on railroads or the like, since the time element does not enter into its disposal as it does when handled molten, and it can be handled virtually without expense in outward bound empty cars, and has in the past been very generally handled in this way by the railroads, without charge, on account of its value to them as a filling material.

The clam-shell bucket for recovering the cinder from the pit is operated in various ways, either by an overhead crane, a crane trolley without lateral movement, or by a locomotive crane running on a standard or broad-gauge track. An arrangement of the latter kind may be seen in Fig. 228, which shows a Brown Hoisting Machinery Company crane engaged in this service. The pit cannot be seen, but

its position can be judged from the ropes running from the end of the boom down to the clam shell which is out of sight in the pit, also by the steam rising from it. The granulated cinder is raised out of this pit and swung over into the hopper cars, steam from which is seen rising on the right-hand side of the picture.

Fig. 229 is a view of the same plant and crane from a different position. The pit may be distinguished by the steam rising from it at



Fig. 230. Browning grab bucket rising out of pit, water draining off.

the extreme left of the picture, while the white granulated slag in the car showing just under the crane boom is plainly visible.

Fig. 230 shows a clam shell operated from a trolley on an overhead runway, installed by Victor R. Browning & Company of Cleveland. The clam shell just at the top of the pit may be clearly seen with the water contained in the slag running from it. The clam shell open, dropping into the pit, is more plainly shown by Fig. 231. In this the perforations in the bucket for allowing the water to run off are plainly visible. The clam shell in its open position with the cars of loaded slag under the runway, are clearly shown by Fig. 232.

A different design but with the same general arrangement by the

same company is shown by Fig. 233. The trolley for handling the bucket with its mechanism and the operator's cage are shown by Fig. 234.

This method of handling slag has the great advantage that it gives several hours leeway, since slag can be stored in the pit without requiring to be removed for a considerable period, so that breakdowns of the



Fig. 231. Browning grab bucket open over pit.

slag handling apparatus may occur without necessitating the shutting down of the furnace.

By providing a pit a little larger than common it would be very easy to store the slag for twelve hours or more, and so eliminate the operation of the slag trolley on one shift. Where the railroads take the slag, and the shifting engine is available for handling empty and loaded cars, this method is more economical for a single or even for a two-furnace plant than the liquid cinder method because it can be run by a single operator, whereas the other requires a locomotive and crew for two shifts as before stated.

Casting the cinder and handling it cold. — In recent years, since the very general introduction of concrete, it has been realized that slag allowed to cool slowly made one of the best aggregates that could be found, much better than limestone, because being of igneous origin it does not break up under the action of heat, as limestone has been known to do in case of fire. Cinder is exceedingly rough and therefore



Fig. 232. Browning grab bucket open over pit.

furnishes an excellent bond for the cement, and in general cinder concrete is very highly esteemed by those who have used it.

Cinder is often recovered for concreting and road filling purposes by blasting the dumps made by ladle cars and loading them up with a steam shovel, but the cinder has generally run out in thin sheets which do not weld together, so that the mass when it is reloaded breaks up into quite small pieces. Moreover, this process requires the double operation of removing the cinder in pots and then picking it up with the steam shovel.

Mr. D. T. Croxton, of the Cleveland Furnace Company, some years



Fig. 233. Browning craneway with trolley and grab bucket.



Fig. 234. Browning man-trolley and grab bucket.

ago, initiated the plan of casting the cinder directly from furnace in the old-fashioned way, but handling it by mechanical means after it was cold, crushing, screening and selling it for concrete material.

After a course of development for several years in which he installed a considerable quantity of special machinery, he finally came to the simple practice of bedding heavy chains into the cinder bed before casting the cinder on to it, these chains being covered up so as to prevent the slag from burning them. The slag bed is served by an overhead crane which, after the slag is cold, takes hold of the ends of the chains at the sides of the bed and pulls them up through it. These chains are spaced a few feet apart and this breaks the slag bed into a material which can readily be picked up by a modern clam-shell bucket and loaded into cars for delivery to the crushing and screening plant.

This system without the mechanical equipment for handling the slag has been in use at other places where the slag has a commercial value as filling or building material.

One considerable advantage of handling the slag in this way is that a magnetic separator can be introduced into the path of the crushed slag and used to recover from it a considerable quantity of iron in pieces from the size of a pinhead up to several pounds weight. This is true even with good furnace practice and where no important quantity of iron is visible to the eye, since the iron is so much heavier than the cinder that it goes to the bottom and is covered over by the latter.

It has been the experience of almost everyone who made any attempt to recover iron from the slag to find more than was expected when the attempt was begun. I had once the pleasant experience of putting in a magnetic separator in the hope of recovering four or five tons a month from a charcoal furnace, and actually recovered fifteen to twenty-five.

Many other methods of handling cinder have doubtless been used and perhaps a considerable number of these are still in operation, but the ones here described cover all the important methods in use on a large industrial scale.

CHAPTER IX

AUXILIARIES AND GENERAL ARRANGEMENT OF PLANTS

IN addition to the apparatus previously described which is required for each furnace there must be a considerable amount of other equipment for the plant as a whole.

It goes without saying that the enormous tonnages involved at modern blast-furnaces can only be handled by first-class railroad track and equipment, both of cars and locomotives, and in sufficient numbers, and that at practically all plants of any size cranes are extensively used for handling heavy parts, cleaning up "messes," and doing innumerable kinds of work that were formerly done by hard manual labor. Very frequently they are arranged to operate grab buckets and magnets, as well as serving for general utility cranes. These are all standard equipment and do not need to be specially described here.

The water-supply system. — The water-supply system is one absolutely indispensable portion of the equipment which, to judge by the location and the design of some plants, was forgotten at the time of their construction and then put in as an afterthought.

The modern furnace depends upon water-cooling for its very existence, not from minute, to minute, but literally from second to second, since the tuyères, coolers and cooling plates are exposed to the most intense heat and the severest conditions of scouring by iron and slag, not occasionally, but in many cases continuously, and only a thin surface of the highest possible conductivity cooled by a violent circulation of moderately cool water prevents their instant destruction.

For this purpose water in considerable quantity must be provided. Its quantity varies very greatly with the size of the furnace and the method of cooling adopted. Cooling plates require more than bosh jackets, and, of course, when cooling plates are used above the mantle they add their quota to the total requirements, since a certain minimum velocity must be maintained for each plate, the minimum depending upon the temperature to which the plate is exposed. For an ordinary 500-ton furnace from 1200 to 2000 gallons of water per minute are required for cooling the tuyères, hearth and bosh.

In addition to this the water necessary for boiler feed, and very generally for condensers, must be supplied, and in modern practice great quantities are being used for gas washing also. This amounts to about 4 gals. for primary cleaning for every 100 cu. ft. of gas or

about 2000 gals. per minute if all the gas is washed. It should be noted that the furnace cooling water can be and generally is used over for either condenser or gas cleaning. The consequence is that each blast furnace requires a very respectable volume of water, from 3,500,000 to 6,000,000 gallons per day, and a plant of several blast-furnaces needs a supply which makes that of many large cities look small in comparison.

Plants have too often been designed with little or no consideration for their location in regard to water supply. There are perhaps more important considerations, such as the arrangement of tracks, etc. — but in a number of cases that have fallen within my own experience a location close to the water supply would have been not only as good but better in other respects than the location actually chosen, at some distance from it, with the necessity of long lines of communication and long-distance supervision of the pumping plant, for, of course, in modern practice long suction pipes are rightly not tolerated, and the pumping plant must be close to the water supply and within a moderate distance above the water level. Moreover, the pumping plant must be able to run and supply water to the furnace irrespective of fluctuations in the height of the supply. These conditions are easy to fulfil if the plant be on the border of a lake or a stream whose level does not greatly fluctuate, but very difficult to meet in some cases where the source of the water supply is a stream with a rise and fall of many feet, such, for instance, as have the Monongahela and Ohio rivers in the Pittsburgh district.

The design of the pumping station must be based on the local conditions and on the size of the plant. Where a very large plant is needed on the banks of such a river it is often desirable, if not necessary, to sink a huge caisson down below low water level from a point high enough above the river level to be out of danger of floods, and run a tunnel of brick or concrete from this out into the river itself. This, of course, requires a cofferdam of some extent for the construction of the tunnel.

The pumps are located at the bottom of the caisson or pit and the flow of water into it is controlled by valves at the inner end of the tunnel so that no matter how high the river may rise the pumps cannot be drowned out.

The screening of the water is done in the pit, no attempt being made to erect screens over the mouth of the tunnel since they would be inaccessible in times of flood.

In other cases a masonry forebay is built at the bank of the river extending well down below water level, its front being entirely open to the river except that it is guarded by screens. These may either be fixed or arranged to be removed for cleaning. The latter, of course,

can only be done by having two separate chambers both of which can be entirely cut off alternately, or by having two sets of screens, one in front of the other so that each one alternately can be raised for cleaning. The possible variations of these methods are of course almost infinite, and the choice of the best one is of great importance because the water supply of furnaces is more apt to be interrupted by floods than by any other kind of accident whatever. The likelihood of dangerously low water can be foreseen, and the necessary arrangements for an additional supply made in ample time, but when a flood arises, especially in a mountainous country, two or three hours may see a change from placid operation to one of absolute disorganization on account of water supply. . This is for the reason that when these violent floods occur the water picks up vast quantities of silt, leaves, and sticks, so that its consistency is almost like soup, in extreme cases, and this combination can stop up a screen in a short time almost as effectively as could a plasterer, while owing to the location of the screens it is not always possible to clean sufficient of their area to let through the water necessary to the life of the plant.

Several years ago, having occasion to provide a water supply for a small furnace near but not on the bank of a mountain river, subject to rises of some twenty or twenty-five feet, I installed a plant designed to meet these conditions which has been very successful in operation, and of which the principle may be useful to others. This plant was described in the April 18, 1914, issue of the *Engineering and Mining Journal*, from which the illustration Fig. 235 is taken.

A forebay of brickwork was built with its base about two feet below the lowest water level, very much as in ordinary construction, but instead of screening this with a straight stationary screen a circular revolving screen was used, which was supported on trunnions built into the masonry. The outlets for the screened water were through the ends of the screen wheel and the side walls of the forebay into the pump pits on each side of it, these suction pits being covered over with iron plates laid in cement so as to be water-tight even when submerged. The screen wheel fitted snugly between the walls of the forebay and was perfectly open in front. At the bottom it passed with bare clearance over a wide sill of concrete running clear across the forebay. At the top it was covered over with a curved plate which fitted down over the top segment of the wheel with small but sufficient clearance. The arms of the wheel were solid plates running from side to side the full width of the wheel, reinforced by angles riveted to the hub as shown in the drawing. The sill and the curved cover plate at the top were a little wider than the space between two adjacent arms.

The wheel proper was made up of welded rings an inch and a half by a quarter, bent edgewise, with half inch spaces between them.

A stout angle across the front of the forebay carried cleaners which worked in the spaces between each pair of rings.

Supposing the pumps to be at work, and the water level somewhere about the center of the wheel, if the lower section of the screen through

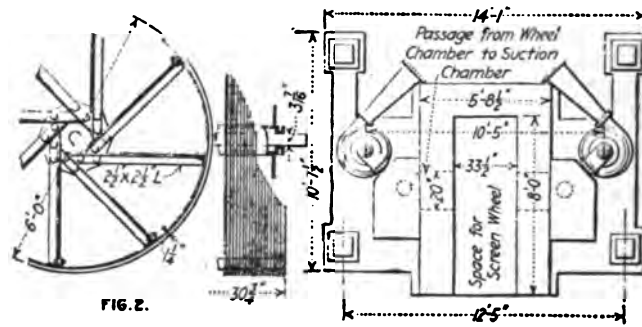


FIG. 2.

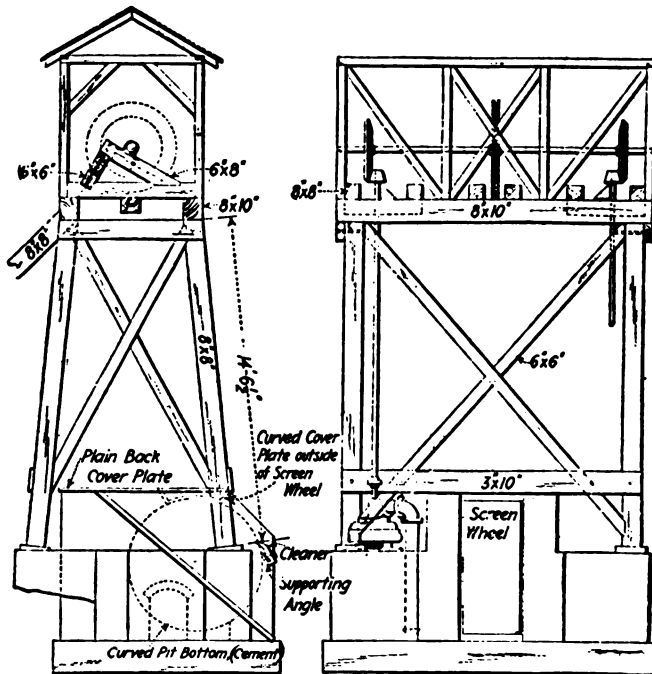


Fig. 235. Self-cleaning screen for pump suction.

which the water is passing becomes obstructed by leaves, the pumps continuing to run, the level of the water inside the wheel is soon lowered well below that of the water outside, and this difference in level then works upon the arms of the wheel which thus virtually becomes an undershot water wheel and rotates the obstructed section downward, thus bringing a new clean section into play. When this becomes

obstructed in turn the same action takes place and when the first section obstructed finally comes around to the cleaners, the leaves, etc., are thrown off by them and the wheel restored to a clean condition.

It will be noticed that centrifugal pumps with vertical shafts are used with their driving mechanism set on a platform many feet above the water level. The driving mechanism in this particular case was by wire rope and bevel gears, there being clutches to throw in or out either pump as desired. Now it would probably be preferable to use a vertical-shaft motor directly connected to the vertical pump shaft. A great advantage of the centrifugal pumps is that they have no valves to become obstructed, and can run submerged for an almost indefinite period. They are located about two feet above normal water level so as to make them easy of access for repairs, etc., under all ordinary conditions.

This plant has gone through several floods in which the screen wheel, pumps, and all were submerged for several feet, and has never failed, as far as I know, under those conditions.

A hand turning gear was provided to rotate the screen by hand if for any cause it should fail to work automatically, and of course it would be a very simple matter to arrange by a geared ratchet or some other mechanism to drive the screen wheel positively and continuously, which might be desirable in some cases.

This wheel was designed for a capacity of about one thousand gallons per minute, for which it was more than ample, and a plant of this kind with a capacity of many thousand gallons per minute could be built at a comparatively small expense. There is no patent on this design and anyone is at liberty to use it who wishes to do so.

Pumping machinery. — Many different types of pumping machinery are used. For small plants and where steam economy is not important, and where the pump installation can receive attendance from the engine room force, direct-acting steam pumps have often been used in the past, in fact, until quite recent years no other type of pumping apparatus was available, except in the largest sizes. As a result different pumps were added from time to time and the number and variety of pumps to be found in the pumping station of some large blast-furnace plants was remarkable.

The direct-acting steam pump is moderately reliable, but not sufficiently so to run without attendance since the pumps may "stick on center," a valve may become blocked open, and various other contingencies may arise which necessitate inspection at frequent intervals. This type of pump is also extremely uneconomical. In the smaller sizes their steam consumption is probably always in excess of one hundred pounds of steam per horse-power hour. In the larger sizes where compounding and triple expansion are used, and where

more refinements can be included in the design, their steam consumption drops to the half of this and often to the quarter, the latter figure being extremely rare except with what may be called pumping engines rather than steam pumps. In all the ordinary sizes the steam consumption is probably never less than fifty to one hundred pounds per horse-power hour.

For larger plants the vertical plunger pump with plungers directly connected to the cross-heads of a triple expansion engine, of the crank and fly-wheel type, with their cranks at one hundred and twenty degrees, are probably as economical as any type of pumping engine driven by steam machinery. They have the great advantage that being vertical, the water cylinders can be placed near the normal water level, while the steam cylinders and driving mechanism are high enough to be out of reach of any possible flood, and in case of a flood the pump cylinders may be submerged and continue to run indefinitely in that condition. These, of course, are necessarily large units and their speed of revolution is limited by the ability of the water to make its way through the valves and follow the plungers which, on account of the inertia of the water, is at a very slow rate. These pumps, therefore, seldom run at more than thirty revolutions, which makes their cost very high in proportion to their output.

In the last ten or twelve years the centrifugal pump with multiple stages has been developed to a high state of efficiency, and instead of being limited to thirty or forty feet lift, as was the old single-stage centrifugal pump some twenty years ago, these pumps are now designed for lifts up to many hundred feet. Their efficiencies with good designs range from seventy per cent. up to eighty in exceptional cases, and while this is considerably lower than the efficiency of a good plunger pump it is maintained through a long period of years.

Questions of leakage scarcely affect these pumps which operate solely by the velocity which their impellers impart to the water, and they are entirely valveless so that under any ordinary circumstances they can run without interruption for very long periods of time.

One word of caution may not be amiss here. The old centrifugal pumps were designed so that they would pass anything up to the size of cabbages, but the modern multiple stage pumps have what may be called a closed impeller with the outlets at its periphery rather narrow, so that sticks of moderately small sizes may lodge in these and cut off the water flow. For this reason screens must be provided with openings small enough to bar anything which could lodge in these discharge ports. The obstructions which will pass these ports are however larger than those which were likely to derange the valves of reciprocating pumps, and centrifugals have therefore the best of

the argument in this very important respect. Owing to their extreme simplicity and to the fact that they have but one moving part, and to the entire absence of valves, these pumps are relatively inexpensive, a result which is attained by virtue of the fact that they are run at very high speeds, and pass an enormous volume of water in proportion to their size.

The master mechanic at the plant at which was installed the pumping plant illustrated above, Fig. 235, assured me with great respect, but nevertheless with profound conviction, that those pumps would "never deliver water enough to supply that furnace." When they were put into operation, however, one of them promptly ran away with the supply brought in by the race from the river; he had to bestir himself to increase the supply, and his doubts were overcome with a vengeance.

Centrifugal pumps on account of their extreme simplicity may be operated practically without supervision or at least receive it only at several hours intervals, there being only a few oil cups to look after. These pumps may be driven by any type of motor desired but for large sizes there are practically only two to be considered. One is the electric motor, the other the steam turbine.

When the pumping plant is located at some distance from the main plant, electrical transmission is to be desired, as motors will run for many hours without attention if properly installed and equipped, so that an occasional visit of an attendant is sufficient, whereas when steam machinery is employed it is virtually necessary to have an attendant on duty all the time, though his work may be of the lightest, 95 per cent. of the time.

In small sizes the electric motor driven from an economical central station is probably more economical than the turbine, because a turbine economical in small sizes has not yet been developed, but in large sizes the directly connected turbine furnishes an ideal drive for these pumps. On account of the very high efficiency of the turbine, especially in view of the fact that a surface condenser may be installed in the water main and a very high vacuum attained without much expense, it is probable that the best type of unit of this kind is as economical in steam consumption as the vertical pumping engine earlier described because the greater efficiency of the turbine offsets the smaller efficiency of the pump, and the cost is only a fraction of that of the engine-driven unit, so that where steam-driven plants are to be installed it may be expected that the turbine-driven centrifugal pump will play an increasingly important part.

In one plant of which I formerly had charge the pumping plant consisted of triplex plunger pumps belt-driven from electric motors, and while the pumps were poorly designed and were too weak for the service for which they were furnished, the combination formed (with this

exception) a very satisfactory plant, and to my surprise the efficiency of the pumps was very high. A test was made of one of them using a large and accurate weir to measure the water, and although the pump was not tuned up for a test, but tested in its ordinary running condition, the efficiency of pump and motor figured out about 85 per cent. Undoubtedly a plant of triplex pumps properly designed and geared to their driving motors would be an effective and satisfactory type of pumping plant where electric drive was desirable, but of course this type of machine does not lend itself to satisfactory steam drive.

The details of these different types of pumping plants are no different from what they are in ordinary service and therefore need not be especially described and illustrated here.

Stand pipes. — The water supply is vital to the life of the furnace plant and must be continuous, since the failure of the water supply on the tuyères for two seconds would almost certainly cause them to be burnt, and only a few seconds more would be necessary to burn the coolers and cooling plates as well. For this reason no amount of care expended to secure a reliable and constant water supply to the furnace is too great.

It is obvious that even with duplicate units in the pumping plant there must be an interruption of a few minutes from time to time in the supply, and it is therefore universal in good modern practice to have a stand pipe with a capacity sufficient to take care of the furnace water supply for a limited period. What this period should be depends upon the judgment or, one might almost say, the individual caprice of the designer of the plant. I have seen some plants at which the stand pipe looked hardly bigger than the smoke pipe of a domestic stove, while at many others it is of the size that would do credit to a large city.

It is probable that the stand pipe should be sufficient to maintain a full supply of cooling water on all the furnaces for at least one hour. Then in case of a serious failure of the pumping plant the furnaces would be shut down and the water supply slacked to a very small percentage of its normal flow and in this way they would be saved from injury for several hours. In case of necessity the tuyères and even the coolers can be pulled if it is obvious that the water supply cannot be restored before the stand pipe supply gives out.

There are three types of stand pipe in common use: first, the straight cylindrical pipe like a stack, second, the elevated tank (generally in modern practice having a spherical or parabolic bottom) supported on a steel tower, and third, a flat tank of relatively small depth placed on top of some building for which it acts as the roof.

The first type is the poorest for the reason that only the upper third of it is useful for storage since when the water falls below that

level the head is insufficient to maintain a proper supply. Or if the tank is built so high that a greater proportion is available then the water must be pumped much higher than is necessary to obtain the desired amount of storage, with consequent waste of power and high cost of equipment.

The second type is that which is commonly used as the stand pipe for cities if no hills are available, and for large plants. The tank is elevated to such a level that its whole contents are available for a water supply, and the excess of the maximum over the minimum height of the water level in it is small, so that not much excess pumping is required.

The third type is not so common now as it was a few years ago, but has much to recommend it, embodying as it does a very large storage with a very small fluctuation in height, and being supported on the walls of the building whose roof it forms, its expense is not excessive, although of course very heavy girders across the building are required to sustain its weight.

At some fortunate plants which receive their water supply by gravity little or no tank is used because of the slight probability of interruption to the regular water supply, there being no machinery to fail.

Water mains.—The character of the water main, like that of many of the other auxiliaries, is determined primarily by the size of the plant. For small plants probably nothing but cast-iron pipe is ever considered, but for larger plants riveted steel mains have sometimes been used, and it is possible that in the larger sizes they are cheaper for a given strength. One point should, however, always be kept in mind in designing mains, and that is that the water which is pumped through them varies from just above the freezing point to eighty or ninety degrees in some districts. The expansion therefore is considerable and means must be provided to take care of it. At one large furnace plant a large riveted steel main was pulled in two by contraction after being several years in service, and the job of making even a temporary repair was a very difficult one, while it could not be permanently repaired except by having the whole plant shut down, a condition which should not exist for many years at a stretch.

This illustrates a point which it is well to bear in mind in connection with auxiliaries, that while each furnace and its immediate accessories are shut down completely at periods ranging from one to three or four years, the plant as a whole, even though it be not a very large one, is not likely to be shut down so completely as to permit stopping the auxiliaries for many years at a stretch. This fact should be borne in mind in laying out water mains, gas mains, electric lines, and sewer systems, particularly the first and last on account of their great size, their being buried underground, the great expense of doing anything

with them, and the vast difficulty of rigging up temporaries to permit repairs to the regular ones.

Returning to the matter of the kind of pipe to be preferred, the cast iron has two very great advantages.

First: Cast iron is less subject to corrosive influences than any of the other ferrous metals, the extent to which it is eaten away being only a fraction of that at which steel is attacked under the same conditions.

Second: A bell and socket cast-iron pipe is laid with a lead joint every twelve feet, this lead being cast and calked to place on a backing of oakum in a way that makes it virtually an expansion joint, so that the expansion of each section is taken up at its ends. No heavy contraction stresses can arise in this kind of pipe, nor can any distortion occur due to cumulative expansion from one end.

Steel pipe, on the other hand, is rigidly fastened together in one piece, and if special precautions be not taken to prevent, the expansion or contraction is liable to be concentrated at one point and cause the failure of the pipe at that point. For this reason if steel pipe be used as a main water-supply system, well-made expansion joints, preferably made on the principle of a huge stuffing box filled with oakum, hemp or other packing, and set up with a gland, should be inserted at such distances as to localize and limit the expansion and prevent its doing damage.

Where large plants are concerned, it is a matter for very serious consideration whether two mains should not be used instead of one, the two together being large enough to supply the whole plant, and one of them able to furnish an emergency or partial shut-down supply. By the introduction of a comparatively small number of duplicate valves permitting both mains to supply all parts of the plant, and at the same time enabling large sections of either to be cut out, provision can be made for repairs to these important accessories without much difficulty or expense, something virtually impossible when a single main is used.

Furnace main connections. — The connections from the water main to the circulating system around the furnace are a matter of the greatest importance, and no amount of care, and no reasonable amount of money is too great to secure freedom from failure here.

It has been my misfortune to experience three partial failures of this kind, and while in every case we escaped without serious damage to the furnace, we were forced to desperate expedients, in one case being compelled to pull the tuyères from the furnace as the emergency supply was insufficient to supply these as well as the coolers and cooling plates; the latter could not be removed without serious delay and so were left in and fed with the minimum quantity of water which would prevent boiling. In this way we managed to prevent the burning of

any cooling member while we changed the fitting in the main supply line which had split but still remained in place, although its limit of life was evidently to be measured by minutes rather than hours.

It is my judgment that two independent supply lines should be used, equipped with the modern type of non-return valves close to the furnace main, these valves being bronze-fitted throughout so as to prevent sticking in the hour of need. These supply lines should be of moderate size so that normally some water would flow through each and keep them both active, while in case of trouble with one the other would deliver an emergency supply. The non-return valves in case of breakage would prevent the water delivered by the unbroken main from flowing back out through the one which failed, and are an indispensable feature of such a design.

Waste water system.— Until within recent years all the water used by the furnace was returned to the sewer so little polluted that it required no special treatment, the water having been used almost exclusively for cooling and condensing purposes, but this is no longer true since the introduction of the gas washer. The wet scrubbing of gas requires a large quantity of water both for cooling and cleaning purposes, and the water discharged from these systems is exceedingly foul, containing the dust from the gas, and also much of the fume which we have been accustomed to consider separate from the dust. In most cases to return this foul water through the sewer system to the original source of supply would be to invite legal action, and it must accordingly be settled so as to remove the greater proportion of its suspended matter. Even after receiving careful settlement it is still quite foul and should not be turned into the main sewer system without careful examination to see that it will not cause the filling up of the latter either by precipitation of suspended material, or by the formation of a deposit of dissolved matter upon the sewer walls.

Where very large quantities of waste water are to be handled brick or concrete sewers are used practically the same as in regular city sewer work, but the branches from these or the main sewer at smaller plants may be of different material. Generally terra cotta pipe is used from about two feet in diameter down, but in many cases square wooden boxes of heavy plank, strongly spiked together, are used very satisfactorily since they are relatively inexpensive, are very durable if located so that they stay wet all the time, and are not liable to be broken by light shocks and heat, as are terra cotta sewers. It is probably safe to say that in nine cases out of ten the sewer system does not receive as much attention in the designing of plants as it should, and is put in as an afterthought, with the result of costing more, and not improbably being worse located than it might have been had it received earlier consideration. Above all, care should be taken to design

small sewers so they can be cleaned by punching without digging them up.

In many cases also where terra cotta is used for secondary permanent sewers it is probable that the greater strength and durability of cast-iron pipe of light section would more than justify its increased cost, since difficulties with a sewer, while they are not very frequent, are inconvenient and expensive to the last degree. Some miserable sewer buried under the ground and never thought of once a year, whose failure to carry off the waste water results in flooding everything, may necessitate the shutting down of the plant for hours in order to cut off or reduce the flow of water while it is being repaired.

One point in the design of the sewer system relative to the plant as a whole is worthy of note. In plants located in northern climates much trouble is sometimes experienced from anchor ice forming on the screen below the water level and shutting off the supply of water. The main waste sewer is normally located to discharge below the pump intake, as is absolutely right and proper, but where this discharge consists of practically clean water which has been used only for cooling purposes the sewer may well be provided with an auxiliary discharge just above the main intake screen of the pumping plant, whereby some of the warm water returning may be discharged at the river bank so as to warm the entering water a little above the freezing point and so serve to cut off or prevent the formation of anchor ice with all its attendant annoyances. These are minor points in the consideration of the blast-furnace plant as a whole, but they are apt to be extremely expensive ones unless given careful thought in advance.

Compressed air supply.— In former times, before electricity had reached its present state of development, a supply of compressed air was one of the greatest conveniences that could be installed at a furnace plant. It was very frequently used for operating bell cylinders, for drilling the tapping hole, for operating pneumatic tools on repair jobs, and many similar operations. For this purpose an air compressor of good design was installed in the power plant, and the air piped to the points of utilization. In good practice branches with valves were inserted in the main at different points so that air could be taken wherever it might be needed, with a short temporary line or hose. Electric power is more economical than compressed air and its general introduction has tended to supplant compressed air installations but the conveniences of the latter is so great that they are well worthy of consideration in spite of somewhat lower economy.

The modern designs of air compressors are greatly improved over those of a few years ago, being more economical and more reliable, and air supplies a very desirable form of power, being absolutely safe and extremely convenient. Especially for repair and construction

work no substitute for the compressed air riveter and other tools of that kind has as yet been discovered. Where compressed air plants are installed as a permanency an after-cooler should always be provided just outside the power house to cool the air to or below the temperature of the atmosphere so that the moisture condensed out of the air by compression may be removed at that point and not go through the line as vapor to condense in some distant pocket where it can make trouble in winter by freezing up.

Many types of compressors have been brought out, and one known as the straight-line type, has had considerable popularity, this is of the same general design as the long cross-head blowing engine, but made horizontal, but compressors are very uneconomical unless they are compounded as to both steam and air. This means two cylinders for each, and therefore the straight-line type must have four cylinders all in a line to embody these features. This makes a rather complicated and extremely inaccessible type of apparatus, and as this type of engine has two cranks and two connecting rods virtually no more machinery is involved to make a cross-compound, two-stage tandem apparatus, with the advantage of vastly greater accessibility and generally a more economical design. The space required, and the foundation cost are greater with the cross-compound type, but its operating advantages are well worth the difference.

Electric supply. — There are still a few furnace plants which are without an electric supply, these are lit at night by oil torches, colloquially known by the descriptive name of "smoke pots," whose light is extremely poor and inconvenience very great, but within a few years the furnace which does not have an electric plant at least for lighting purposes will be a thing of the past. At practically all modern plants so much of the work is done by electricity that an electric plant of considerable size must be provided. In many cases the electric stock hoist and electric bell hoist are used, and pumping plants, lights, and many other minor but necessary auxiliaries of the furnace are operated by electricity.

Where the furnace plant is connected with steel works the electric plant of the combined works becomes enormous. That of a steel works of two or three thousand tons daily capacity is probably as large as that of the average city of half a million people. The electric plant for the blast-furnace does not differ essentially from electric plants for other uses and must be designed primarily with reference to its size and the service to be expected of it, never forgetting that on account of its convenience other duties will be hung on to it from time to time, and that the plant which does not start with a hundred per cent. reserve capacity will probably soon be too small to do what is required of it.

Where very large electric plants are to be installed it is still a question as to whether the gas engine or the steam turbine is the more economical. The gas engine is undoubtedly the more economical by twenty-five to thirty-three per cent. on the heat unit basis, but its operating cost is decidedly higher, and its fixed charges are very much greater than those of the steam turbine. It is therefore very largely a matter of local conditions. If coal be high, intelligent labor plentiful, and capital not too dear, the gas engine is to be preferred. When these conditions are reversed undoubtedly the steam turbine is the better. The intermediate conditions must be decided on their merits after careful examination of all the factors.

The steam turbine has one great advantage in that it may be used as a low-pressure machine exclusively, and in two of the most modern plants which combine both blast-furnaces and steel works the blowing engines are steam-driven, and exhaust their steam about at atmospheric pressure into turbines which drive the electric generators. The turbine is by far the most economical motor in existence for low pressures, while it is inferior to the piston engine at higher pressures. This arrangement places each type of machine under the conditions for which it is best adapted, and makes a type of plant which has everything to commend it when the electrical requirements are sufficient to use up the steam from the blowing engines.

In smaller sizes the electrical plant may be either steam engine or turbine-driven, the steam engine probably being preferable in small sizes and the turbine having an increasing advantage as the size of the plant increases.

Voltage and kind of current to be selected. — The voltage and kind of current, direct or alternating, to be preferred depends on the local conditions. For small plants two hundred and twenty volt direct current gives excellent satisfaction. This voltage is high enough to keep the cost of copper in transmission lines within reason, and is low enough to give good service with incandescent lamps, while for electrical machinery which requires much control, such as cranes, ore bridges and the like, direct current still seems to have the advantage over the alternating on account of the ease of reversal, speed control, dynamic breaking, etc. At large plants where the power is transmitted in great quantities the direct current is out of the question except as an auxiliary. The alternating current must be used so that it may be stepped up to any voltage desired for transmission and stepped down at the point of utilization. If direct current be required for crane service or the like, it is produced by motor generator sets or rotary converters. When alternating current is used different voltages may be used in different services to suit the individual conditions. For mill motors and the like where men are likely to come in close contact

with them four hundred and forty volts or less are used, whereas on large motors such as those which drive rolling mills direct, voltages from twenty-two hundred up to sixty-six hundred are used.

GENERAL ARRANGEMENT OF PLANTS

The general arrangement of furnace plants. — In early days blast-furnaces were very generally built singly, plants of two were scarce, and a greater number than that in charcoal practice were almost unknown. But as the world's consumption of iron has risen the number of furnaces per plant has increased almost as rapidly as the tonnage per furnace, there being two in the United States with eleven, many of six and seven, and only a small portion of the total furnaces are single furnace plants. This fact has modified the general design of plants fundamentally. It is obvious that when a furnace stands alone the different elements of the plant as a whole may be arranged in almost any relation to one another, but when two or more are grouped together it is plain that their raw materials should come in by a means of transportation common to all, and that their output should be similarly taken away. Also that labor can be saved by grouping certain components of the equipment of each furnace together, notably the blowing engines, boilers, and stoves. The first two can be supervised by the same men, and the third sometimes are. In considering the arrangement of furnace plants, therefore, we need scarcely to consider plants of less than two furnaces, because as stated above the equipment of the single furnace can be arranged in almost any reasonable way and meet the conditions fairly well.

On account of the enormous quantities of materials handled it is obvious that the best possible arrangement of the railroad tracks must be at the basis of any proper design, and all multiple furnace plants for many years past have virtually had the stock houses for all the furnaces continuous, all being served by the same set of tracks. These, for obvious reasons, are made straight except in rare circumstances, and should always be so. This virtually forces the furnaces to be built in a straight line parallel to these stock house tracks.

The next points in the design involving the handling of a heavy tonnage of material are the casting arrangements and the cinder pits, and here it took many years to reach a sensible design. Probably the greatest defect of all our designing is a tendency to put every part of the design either at right angles with or parallel to the next element, and plants have in general been laid out with their parts at right angles with or parallel to the other parts. The fact which seems to have escaped observation is that railroads do not run around right angles, and therefore with one part of the plant at right angles to another if the first were parallel with the tracks, the second must be at right angles

to them, and therefore relatively inaccessible. In spite of this the line of the cast house was for many years built at right angles to the line of the stock house tracks, and in order to bring cars alongside the cast house to permit the direct loading of pig iron these tracks all had to make a sharp right-angle turn. Even worse is the fact that, as the curves must all be turned off in the same direction, they can turn to a tangent along the near side of the cast house wall, but can only approach it with great difficulty on the far side, a very disadvantageous condition.

A little careful consideration will show that there is no fundamental reason why the cast house should be at right angles to the stock house tracks, and when the first pair of Lorain furnaces were built an attempt was made to evade this difficulty by turning the cast houses toward one another, so making them parallel to instead of at right angles to the stock house tracks. This somewhat increased their accessibility, but took up much room, since obviously the two furnaces were more than the length of both cast houses apart.

Various modifications of the right-angle plan were used, but without reaching any design which met the conditions satisfactorily. When designing the plant of the Federal Furnace Company of Chicago, Julian Kennedy adopted a plan which will undoubtedly be more and more used, though often in modified form, as time goes on, he placed the line of the cast houses at a diagonal with the line of the stock house. Fig. 236 shows a ground plan of these works on which the names of the different parts are clearly marked so that the arrangement is easily comprehensible. It is obvious from this plan how easily all parts of the plant are reached by railroad tracks with short and easy curves, and it will be equally obvious on a little reflection that if the cast houses had been placed at right angles to the line of the stock house trestles, in the old-fashioned way, their far sides in particular would have been almost inaccessible to railroad tracks within the available yard limits.

A further development of this idea took place when the Gary plant of the Indiana Steel Company was designed. A small scale plan of this plant reproduced from *The Iron Trade Review* is shown at Fig. 237 (page 377). The scale is so small that some study is necessary to distinguish the different parts, but this can be done with a little pains.

In this case the cast houses were turned to an angle of about thirty degrees with the center line of the row of furnaces. The angle of the skip was made flatter and the base of the skip bridge further from the base of the furnace than in the Federal design so that tracks could be run along between the under side of the skip bridge and the foundation of the furnace itself, which greatly increases the accessibility of all parts of the plant to switching service. These tracks underneath the

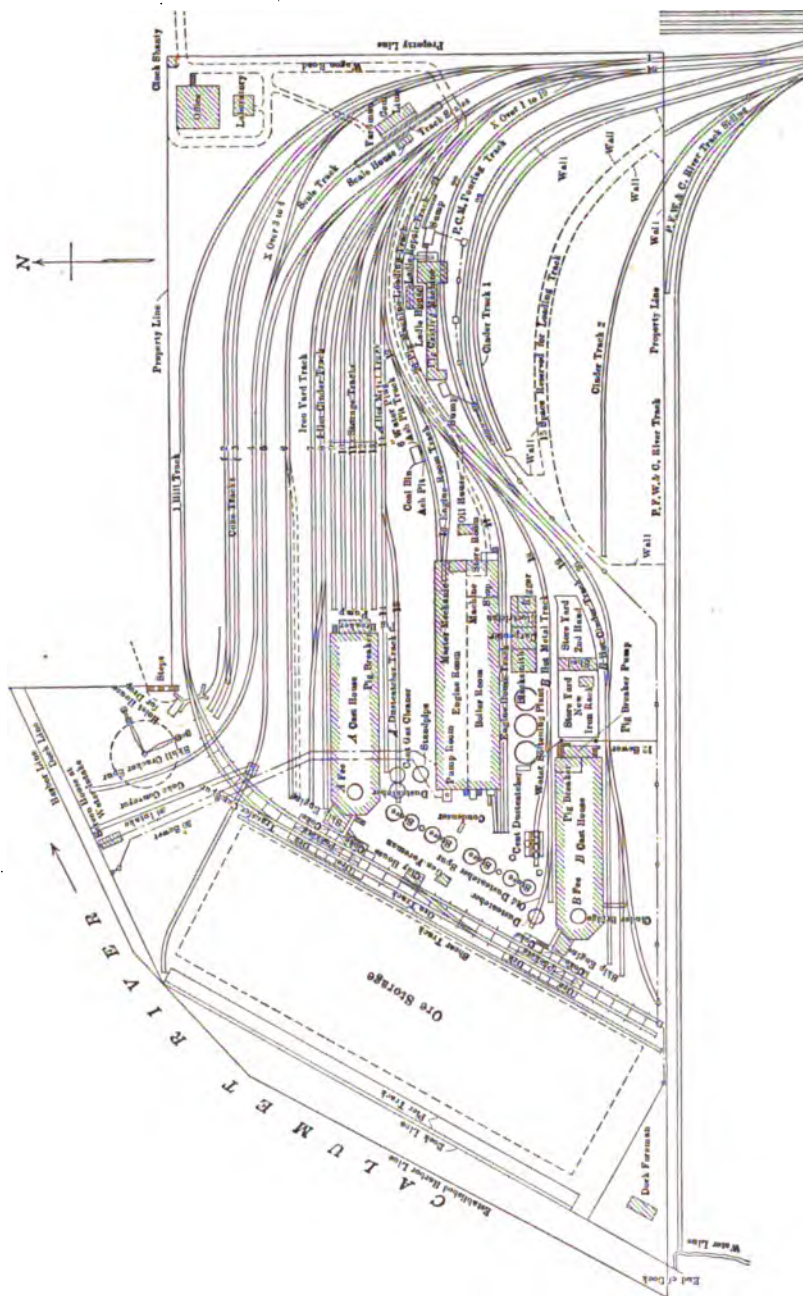


Fig. 236. General arrangement of Federal Furnace Company's plant.

skip communicate with the other tracks in front of the furnace by ladder tracks between every second pair of furnaces, which run through diagonally on the same angle as that of the cast houses. These tracks serve not only the cast houses, but the dust discharges of the different dust catchers as well. In this case each pair of furnaces becomes a lozenge shaped island in a wide river of tracks, with practically every part of the plant within easy reach of at least one track. It is seldom wise to prophesy finality in any technical matter, but the general principle of this design is so nearly perfect that it seems likely that it will eventually come to be the only plan considered for multiple furnace plants, but, of course, modifications to suit individual conditions or changes in the component parts of the plant may be made in every case.

The distance apart of the furnaces.— This is controlled by various circumstances. When the ore supply for the large part of a year has to be stocked that becomes one of the controlling factors because the cost of ore bridges increases very rapidly with their length, and commercially their practical length is limited on this account, also by the great time required to traverse the trolley from one end to the other of a long bridge. The height of the ore pile is limited by considerations affecting the cost and strength of retaining walls at the sides of the stock pile, and the slope which the ore takes running back from them. The pile is thus limited in two dimensions, and in order to store a given tonnage of ore the required volume must be obtained by making the length of the pile per furnace as great as is necessary, and this length is obviously the minimum distance between furnaces, for those conditions.

There are many other considerations affecting the spacing of the furnaces, however, especially in those cases where considerations of the size of the stock pile do not control them. It is very undesirable to have the furnaces crowded together as it is more difficult to work around them under those conditions, more damage is likely to be done to one furnace by an accident at another, and questions of accessibility of various kinds arise which it is practically impossible to provide for in detail in advance, and which can only be met satisfactorily by having a certain amount of room around each furnace.

On the other hand, it is undesirable to have them spaced too far apart on account of the initial expense of land, tracks, etc., and such spacing not infrequently defeats its own ends by offering a temptation to put something into the unoccupied space, another furnace or some other part of the plant. This has happened on more than one occasion. The supervision of furnaces is also more difficult when they are scattered over too wide a territory. One blower can frequently blow two furnaces if they are spaced close together, but would not be close

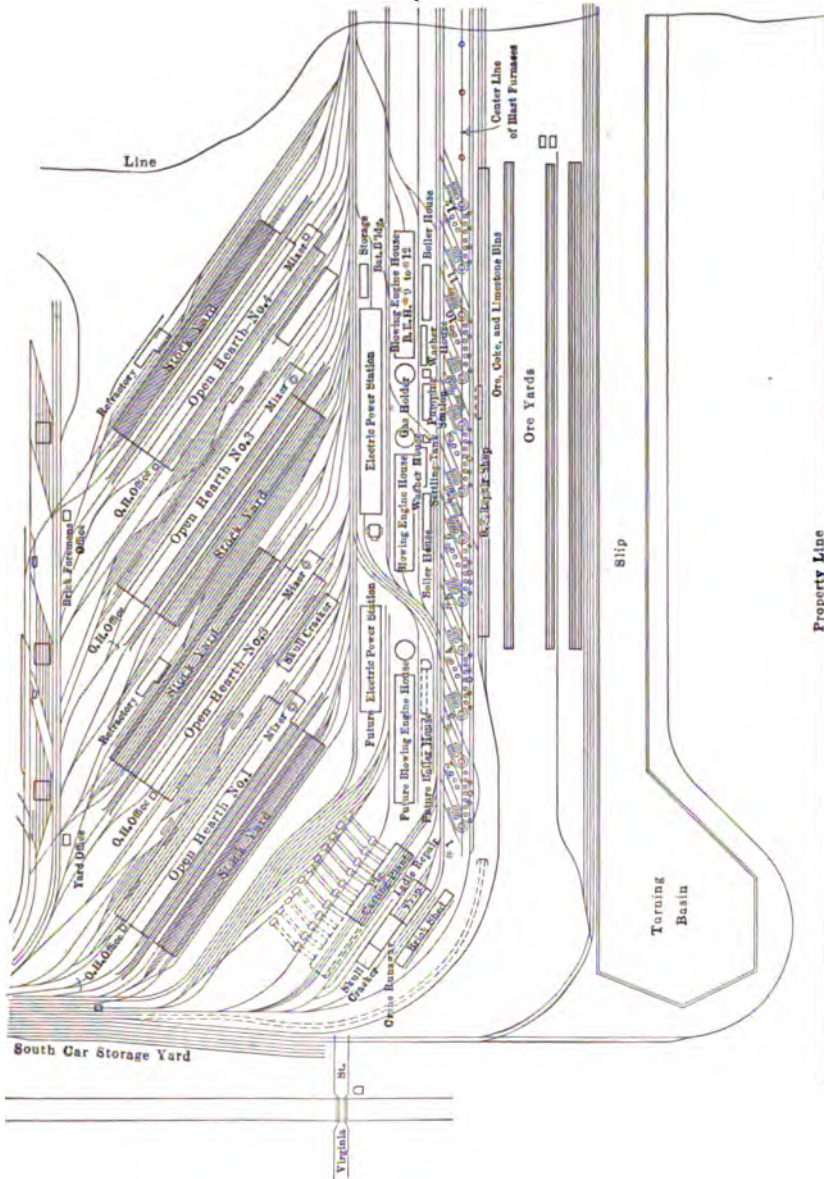


Fig. 237. General ground plan and track layout for the plant of the Indiana Steel Company at Gary, Ind.

enough to the work to manage two located very far apart. When the stoves for each of a pair of furnaces are arranged in a continuous row as shown in Fig. 236 this in itself controls the minimum distance apart of the furnaces, as it virtually does at that plant.

Furnaces are very generally arranged in pairs, rights and lefts, as shown in Fig. 236, and more clearly shown in Fig. 238, which illustrates the arrangement of a pair of furnaces with their stoves, gas

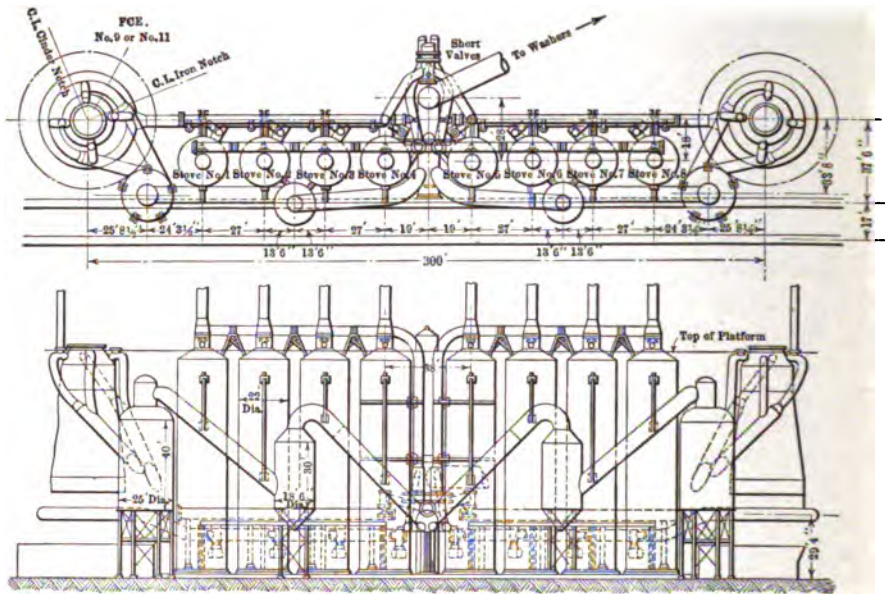


Fig. 238. General ground plan and elevation of a pair of furnaces with their stoves and dustcatcher. Indiana Steel Company, Gary, Ind.

main, etc., in some detail. On the other hand, at one of the best built and most successful plants the plan was adopted of having the furnaces all built the same "hand," that is to say, looking at the plant from the front, the stoves are all on the left-hand side of their respective furnaces.

One of the advantages of the pair arrangement is that it makes the distance between furnaces alternately very short and quite long. The close grouping of one pair of furnaces is an advantage since that is about the limit of what a single blower can supervise satisfactorily, and having these two close together makes it possible for him to keep in much closer touch with their operation. The fact that the next pair is several hundred feet away is of no importance whatever to him.

The arrangement of the stoves and hot-blast main.— This is a subject deserving the most careful consideration. Stoves in modern practice are universally arranged in one straight row, where considera-

tions of room permit, but this exposes the maximum amount of surface to radiation, takes up the most room, and requires the longest hot-blast main.

About thirty years ago the late Samuel Thomas built the Pioneer Blast-Furnaces now owned by the Republic Iron and Steel Company in Birmingham, with the four stoves at the four corners of a square, with the hot-blast main running between them. This takes up much less room than the linear arrangement and shortens the length of the hot-blast main by the diameter plus clearance of two stoves, and where room is a matter of importance this plan is worthy of serious consideration.

The location of the stoves in relation to the furnace is a matter of much importance from another point of view. The hot-blast main becomes heated to quite a high temperature in spite of a heavy lining of firebrick, and as a result expands in ordinary cases from one to three inches. No expansion joint has as yet been designed that is satisfactory for this service on account of the high temperature to which it is necessarily more or less exposed, and in consequence one end or the other of the hot-blast main must move. Owing to the construction of the hot-blast valve seats shown in an earlier article these act as expansion joints to the extent of about half an inch or an inch. That is, the main can slide on the flat surface of the joint to this extent without breaking anything. The bustle pipe is suspended from the furnace itself on swinging hanger bolts, and these are free to move more or less, but movements of the bustle pipe in relation to the center of the furnace are extremely undesirable because if it was put up truly concentric with the furnace originally every change must move it from the center, which means that the distances from the base of the tuyères to the bottom of the penstocks is not constant, as it should be, but longer on one side of the furnace than on the other. This necessitates having special blow pipes for some or all of the tuyères and greatly increases the spares necessary to be kept on hand, and, what is even more important, increases very greatly the difficulty of changing tuyères or the like on account of the difficulty of securing the right length of blow pipe.

For these reasons the design of the hot-blast main, particularly in relation to expansion, should be very carefully considered before a final plan is adopted.

The elevation of the furnace.—Furnaces in the early days were set practically flat on the ground and their operating level was the general ground level, it being possible to walk about them without the use of stairs of any kind. But the tendency has steadily been to raise the furnace proper higher and higher above the ground level, primarily to permit placing ladle cars under the spouts delivering the

iron and cinder from the cast house. Many low-built furnaces were equipped for handling cinder in hot pots by digging deep pits for the ladle tracks and running down into these on a sharp grade. This is a way out of the difficulties which arise by not having sufficient height but it is an exceedingly poor one, because it increases enormously the difficulty of pulling the cars out of the pit and of handling them in it. Moreover, if a "mess" occurs, as it occasionally does in spite of the best management, the cinder and often the iron flow into the pit, or fill up the ladles, and then overflow them, running down into the pit itself and making in some cases a pool two or three feet deep of molten iron and cinder at the bottom of a deep pit with masonry walls. The task of removing this, which is absolutely necessary before the furnace can be put back into operation, is bad enough to contemplate but much worse to experience, while the expense of the delay and repairs to tracks are very heavy.

Even where the pig iron is handled cold, by hand, it is extremely desirable to have the cast house set well above the level of the iron shipping tracks, very frequently transfer trucks are used in taking the iron from the cast house to the iron scales or the storage yard, or to the broad-gauge cars for final shipment, it is of course important to be able to drop the iron down to these transfer cars and also to drop it again to the standard-gauge cars. All of these considerations have demanded that furnaces be set higher and higher with the result that the hearth level at modern furnace plants is from 15 to 20 feet above the ground level.

The tracks serving the cast house and the cinder runners instead of being of the "dead end" variety as they must be if they are in pits, are, if possible, always made through tracks on the ground level, so that if there be an obstruction in one direction the liquid iron and cinder may be hauled away in the other.

It is probably advisable to go even a step further than this and to have the level of these tracks where the ladles stand on them raised a little above the level of the surrounding territory so that in case of a breakout or other accident the runaway iron and cinder instead of forming a pool on top of the tracks, to their complete destruction, may run down hill off of them.

The arrangement of the boilers and engines. — The blast can be carried for very considerable distances from the blowing engines without much loss of pressure and with but little expense. It is therefore possible to locate the blowing engine house at a considerable distance from the furnaces, but of course it is very undesirable to carry the steam any further than is absolutely required. This means that the boiler house must be located close to the engine house, and as the gas from the furnace must be brought to the boiler house the location of the latter is deserving of considerable study.

At small plants attempts have been made to set boilers and stoves close together so that one man could attend both sets of burners, and this is, on many accounts, an excellent idea, but cannot generally be followed at larger plants, and therefore a location is chosen for the boiler house which will give the shortest and most convenient gas main to reach it and at the same time give the best steam connections to the engine house. It might almost be said to be standard practice to put the engine house and boiler house parallel and close to one another, although very many plants have departed from this practice for one reason or another.

Where room is an important consideration these two buildings can be placed in spaces relatively difficult of access without much detriment because very little material has to be hauled to or from them on railways, but, of course, provision must always be made to bring in an ample coal supply for the boilers even though it be useless 95 per cent. of the time.

It is almost indispensable that the engine house should be served with a track to handle the heavy parts of blowing machinery during erection and subsequently during repairs, but these tracks being very little used need not have the location and alignment required for tracks carrying a continuous and heavy traffic.

The number of furnaces served by a single blowing plant must be decided by the general arrangement of the plant along the lines laid down above. The expense of carrying the blast is, as there stated, not very heavy. At the same time if it were attempted to supply blast for a large plant of eight or ten furnaces from a single blowing engine house the quantity of piping involved would become very large, and the room which these pipes would take up running, in many cases, close to one furnace in order to reach others would be a very serious matter. For this reason it is possible that four furnaces is about the limit of the number that can be advantageously blown from a single engine house. Moreover, it is to be noted that when the number of engines in the plant has reached the limit of what one given crew can supervise adequately another crew then becomes necessary, or a large portion of one, and it makes little difference in the operating cost whether these be in one house or in two, while it makes an enormous difference both in cost and in room required if blast pipes for more than four furnaces have to be distributed from a single blower house.

The electrical, compressed air and dry-blast plants are almost always located, as they should be, in or adjacent to the blowing-engine house so as to be under the charge of the blowing engine operators, and served by the cranes installed over the blowing machinery. The feed pumps for the boilers were formerly in the same building but are now very generally placed in the boiler house proper and put under the

charge of the boiler house attendant. The pumping plant must be located primarily with relation to the water supply, and while it is exceedingly desirable that this also should be in the main power house it is not always possible to arrange it in that location without sacrificing even more important considerations. At the same time the cost of attendance of isolated plants of relatively small power is very high as compared to that in a single large power house, and for this reason the pumping plant should be either in the main power house or as close to it as practicable.

Arrangements for the disposal of the iron.— These necessarily vary according to the purpose of the plant. If it be a component part of a steel works then the prime consideration is safe and convenient methods of hauling the ladle cars to and from the steel works. If on the other hand the furnaces constitute a merchant plant all the iron is required to be cast either in beds or a pig machine. In the latter case the location of the pig machine is a matter of some moment as is also the location of its service tracks. In an earlier chapter were given a description and illustrations of a pig machine plant with an excellent arrangement of "ladder" tracks. Such an installation can within reason be located wherever consideration of tracks and space require.

The disposal of the slag.— The prime consideration in this is that the runners shall be short since even the hottest and best-running cinder builds in the bottom of the trough and has to be cleaned out and disposed of before the next flush. The labor required for this increases almost as the square of the length of the trough and it is therefore very important to keep the latter as short as possible whether it is to discharge into a hot pot or into a granulating pit.

The location of the slag dump for the final disposal of the slag may be any distance up to one or two miles or even twice as much, but of course it is desirable to keep this distance as small as possible in order to diminish the time of the ladle cars and locomotives on the road and so enable the smallest number of them to perform the necessary service.

CHAPTER X

THE DRY BLAST

THIS subject has aroused within the last ten years more comment and controversy than any other connected with the blast-furnace. In dealing with the thermal principles of the furnace I shall endeavor to show that the claims for economy made on behalf of the dry blast are well founded, and in treating with the question of operation I shall endeavor to discuss the considerations other than those of fuel economy which affect the subject and must be considered before reaching a correct decision in regard to this matter. Here we have only to do with the design and construction of the plant if its installation be decided upon.

It is well known that the atmosphere contains moisture, but the laws under which the moisture exists are probably less widely understood than any others dealing with a subject which affects our daily life so much.

According to Dalton's law two or more vapors or gases can, in fact and in principle, occupy the same space at the same time, and each acts exactly as though the other were not there. That is to say, if we have two cylinders holding one cubic foot each, one of them containing nitrogen sufficient to exert a pressure of twelve and a half pounds per square inch on the inner surface of the cylinder (that is, not pressure above the atmosphere, but absolute pressure) and another containing oxygen sufficient to exert a pressure of two and a half pounds per square inch absolute, and pump the contents of the second cylinder into the first, each gas will continue to exert the same pressure that it did before, but in this case they will both be exerted on the walls of the same cylinder, and we shall have a nitrogen pressure of twelve and a half pounds, plus an oxygen pressure of two and a half pounds, or a total of fifteen pounds per square inch. Similarly if we have a cylinder containing a cubic foot of water-vapor at an absolute pressure of half a pound per square inch, and pump that into the first cylinder, we shall have a total pressure of fifteen and a half pounds per square inch, and if the cylinder were opened part of the mixture would flow out until the total pressure was down to atmospheric pressure, but the gases and the vapor would be present in the same proportions as before.

This on the assumption that the temperature is high enough to produce a vapor pressure of half a pound, and here we come into com-

plications because the pressure of the vapor depends entirely upon the temperature, or at least is limited absolutely by it. It can never be more than the pressure corresponding to the given temperature, but it may be, and in the atmosphere generally is, less. For our present purpose it seems to me to simplify matters to consider the air not as *containing* vapor but as acting simply as a carrier for it. That is to say, if we handle ten thousand feet of air the water-vapor in that air must go with it, though not in the chemical sense dissolved therein.

The determination of the quantity of moisture actually present in the atmosphere may be made in several ways. The simplest is to cool very slowly, by some form of artificial refrigeration, a glass or metal cup or vessel containing a thermometer and note the temperature at which visible moisture begins to settle upon it. This is known as the dew point, and knowing this we can easily take the weight of vapor per cu. ft. directly from the vapor tables, which the United States Weather Bureau publishes in very comprehensive and satisfactory form. This, however, is not the method generally recommended for obtaining the dew point. As the result of very extensive investigations it has been stated by practically all the authorities that the wet-and-dry bulb thermometer furnishes by far the most satisfactory and reliable information. The theory of this instrument and the tables for its use have been set forth very thoroughly both in government publications and in a paper by Mr. W. H. Carrier of Buffalo before the American Society of Mechanical Engineers, in Vol. 33, 1911, the latter being particularly valuable.

The quantity of moisture in air is usually given in grains per cubic foot, but this is an exceedingly unsatisfactory unit for blast-furnace work because the other quantities with which we are concerned are measured in tons and pounds, but certainly never in grains, and as the effect of water-vapor is purely a quantitative one it is very desirable to have it expressed in the same units as those used for other quantities involved in furnace operation. For this purpose pounds per thousand cubic feet of air are by all means the most desirable, and as there are exactly seven thousand grains in a pound avoirdupois we have only to divide the grains per cubic foot of the ordinary tables by seven to convert the results to pounds per thousand cubic feet.

Here a point of much importance arises. Air is very commonly measured at 32° F., but when its temperature is raised to say 70° F. its volume is increased about 8 per cent., and as the quantity of moisture increases directly as the volume, the moisture content of a cubic foot of saturated air at 70 is greater than that of the same weight of air at freezing, not only because of the increased density of the water-vapor but because the carrying space in which this vapor exists is simultaneously increased.

In 1906, soon after the first announcement of the success of the dry blast, I published before the (British) Iron and Steel Institute, a paper entitled "Different Modes of Blast Refrigeration, and their Power Requirements," in which was given a chart showing the weight of water-vapor per 1000 cu. ft. of air at temperatures from minus 20° to plus 80° F., but as this question of cubic feet is very troublesome, because we must always state the temperature at which the air is supposed to be measured, I converted this to 75 lbs. of air, which is the weight of atmospheric air at 70° F. and standard barometer. This chart is shown in Fig. 239, from which it will be seen that the moisture content at saturation per 75 lbs. of air rises from 0.07 lb. at zero F. to 1.14 lb. at 70° F.

As normal air is about two-thirds to three-fourths saturated and as the temperature in summer may easily rise to 85°, it is very obvious that we have in summer to deal with moisture sometimes reaching a pound or more per thousand cubic feet, and such is the case in many northern iron-producing districts, the **average** moisture for some months being nearly a pound, while in Alabama the conditions are much worse than this, a pound and a half per thousand cubic feet being not unusual.

Accepting it as proven for the present that the action of moisture on the operation of the blast-furnace is exceedingly detrimental, and realizing that the above figures indicate that we may easily be pumping 50 lbs. or 6 gals. of moisture per minute into a modern furnace with the blast, the question obviously arises, how shall we eliminate it?

The metallurgical world now knows how the question was solved after many years of experiments by James Gayley at the Isabella furnaces in Pittsburg, the moisture being condensed out of the air by artificial refrigeration. Obviously, since the quantity of moisture in saturated air rises with great rapidity with rise of temperature, as shown in Fig. 239, we have only to lower the temperature to cause the precipitation of the moisture. In practice we have to do more than this, since lowering the temperature tends to precipitate the moisture as fog, which, in its form of water mechanically suspended, may easily pass with the rapid current of air through the refrigerating apparatus and thus to the blowing engines and the furnace. Care must therefore be used in the design not only to condense the moisture but to precipitate it out in drops large enough to leave the air. Preferably the drops should form on the refrigerated surfaces and drip from these in such a way that the air current cannot pick the drops up again.

Refrigeration requires power, and what is more serious it requires investment of capital. Therefore it is very important to design the refrigerating plant to use the least amount of power possible since

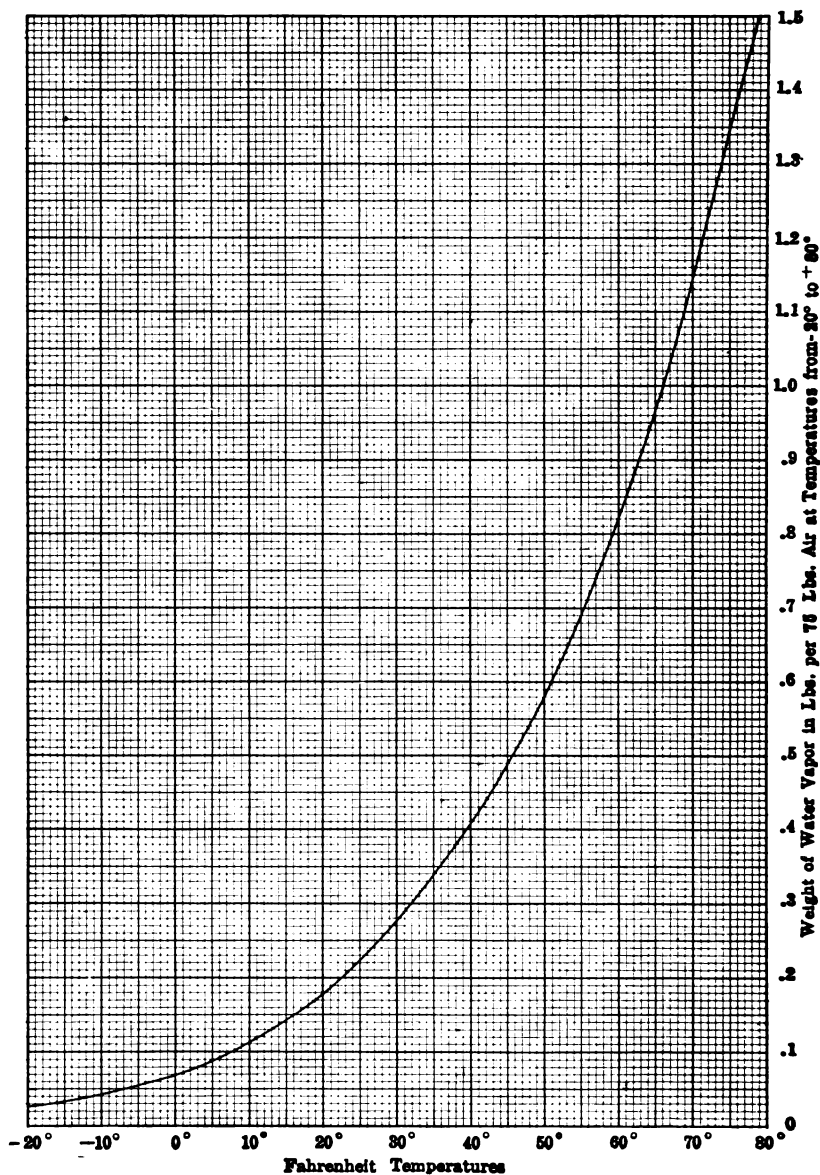


Fig. 239. Chart showing weight of water-vapor per thousand feet of air at saturation at different temperatures.

this will in general mean the smallest capital cost also, and the capital cost of this process has been its greatest disadvantage.

The original dry-blast plant, that at the Isabella furnaces of the United States Steel Corporation, was of the brine circulation, single-stage type for the reason that in the vast metallurgical experiment upon which Mr. Gayley was engaged, he felt compelled to take the simplest and easiest means to accomplish the result, irrespective of whether they were the most economical, and on account of the success of this system at the Isabella plant, and of some failures of early attempts to improve upon it, the same system was used for all the early dry-blast plants. Briefly this system is as follows:

The ammonia vapor is compressed by a steam-driven compressor and condensed in a standard ammonia condenser, from which it passes to a brine cooler where it is evaporated, absorbing the necessary heat for evaporation from the brine and thereby cooling the latter. The brine, a solution of salt or calcium chloride with a freezing point many degrees lower than that of water, is then circulated through other coils in a huge chamber through which the air passes on its way to the blowing engine, the air being blown into the chamber by a large fan and removed from it by the suction of the blowing cylinders. Ice forms on the coils, which soon reduces their cooling power and obstructs the passageways for the blast. This necessitates putting out of commission each of the coil chambers in turn every few days while it is thawed off by steam, an expensive operation since not only the steam but the ice, cost coal, and the operation of thawing itself takes some time and labor.

A plant of this type designed by Frank C. Roberts & Co. is shown by Fig. 240. The captions under the different views render them very easy of comprehension.

A careful study of the refrigerating process makes it obvious that this system of refrigeration is capable of great improvement, both from the point of view of first cost and that of power requirements. The general principles controlling this whole matter were pointed out at some length in my paper before mentioned, part of which is reproduced below.

It is well known that the power required for a given quantity of refrigeration per minute, Q , is theoretically proportional to $\frac{T_1 - T_2}{T_1}$ where T_1 is the absolute temperature (Fahrenheit + 460 deg.) at which the heat is absorbed by the system and T_2 that at which it is rejected, the expression being

$$\text{HP} = \frac{778}{33,000} Q \frac{T_1 - T_2}{T_1} \quad (1)$$

where Q is measured in B.t.u. per minute.

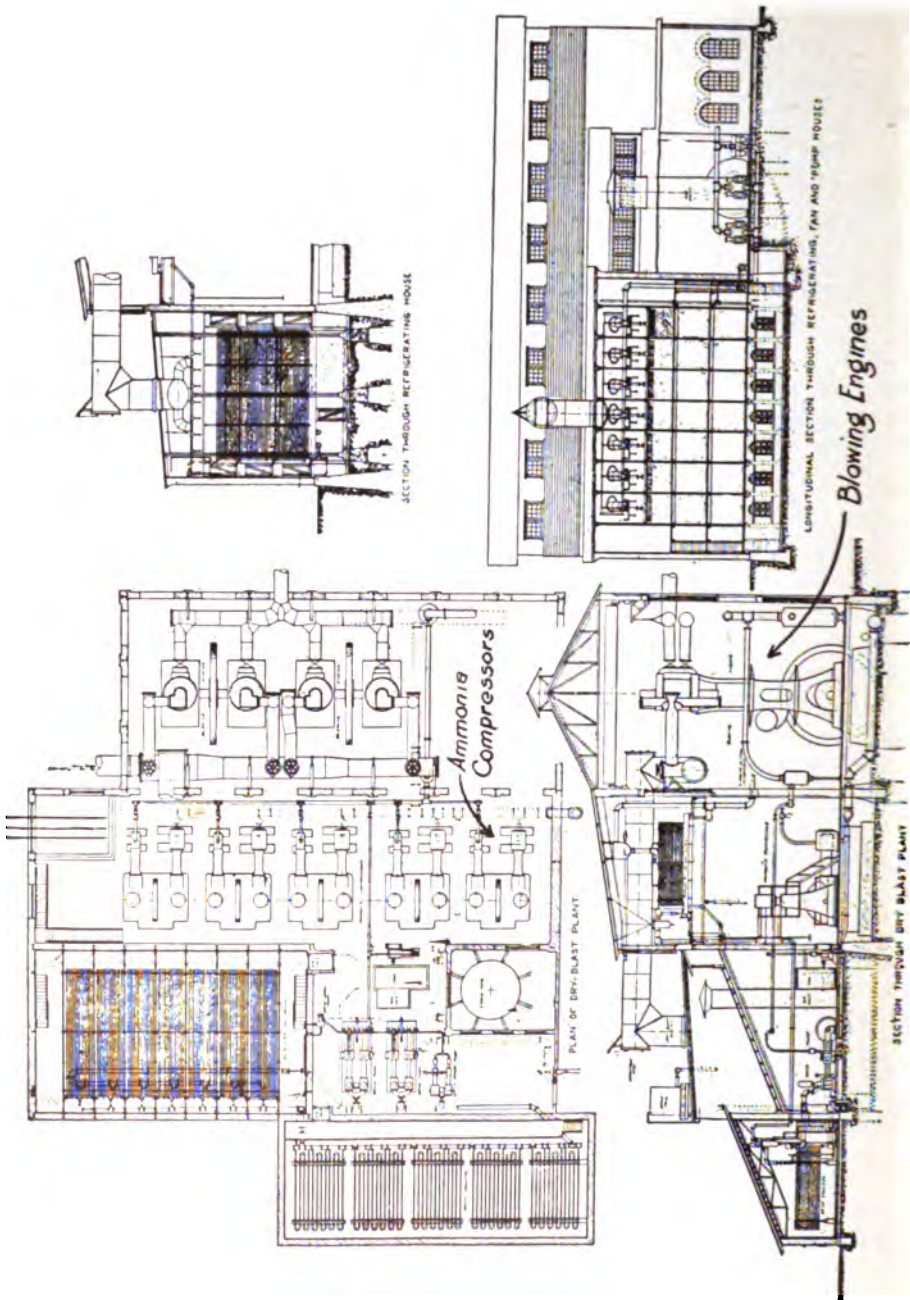


Fig. 240. Dry-blast plant designed by Frank C. Roberts & Co. Single stage, brine-circulation, non-regenerative.

The ammonia-compression refrigerating machine having so largely supplanted all others for land service, we shall consider only that type. Upon it, fortunately, reliable investigations have been made which enable us to establish a relation between its theoretical and its actual performance, and this goes far towards answering our questions.

For a number of tests in each of these series I have calculated the theoretical horse-power by equation (1), and compared it with the actual indicated horse-power of the steam cylinders, the ratio of the latter to the former being called R , it being, in fact, the reciprocal of the efficiency on this basis.

These values of R have been plotted as ordinates with the corresponding values of $\frac{T_1 - T_2}{T_1}$ as abscissae, as shown on Fig. 241.

The values of R plainly decrease with the value of $\frac{T_1 - T_2}{T_1}$, and it is clear that when the temperature range is zero, R should be 1, the efficiency being perfect. Accordingly, a straight line has been drawn passing through the point $\left(\frac{T_1 - T_2}{T_1} = 0, R = 1\right)$ and this line coincides with the points with surprising accuracy, and may be taken as expressing the law of this relation correctly.

As these tests represent widely varying conditions it is clear that there is a trustworthy connection between the conditions of refrigeration and the power required for it in any case.¹ The algebraic expression of these values is $R = 1 + 4.15 \frac{T_1 - T_2}{T_1}$.

The relation between temperature range and power requirements for a given quantity of heat having been determined, we need only

¹ Although this seems such an obvious means of determining the actual power requirements in any case, when the general conditions are known, it is entirely new, and has never been used by refrigerating engineers, so far as known to me.

In the original paper reference was made to the work of Professor Denton in New York and Professor Schroter in Munich on tests of the power consumption of refrigerating machines, but a much more extensive series of tests have since been conducted by the York Manufacturing Company, under the direction of Mr. Thomas Shipley, its general manager, and the results of these tests have been collected and plotted in a paper on "The Power Required for Refrigeration" (*Metallurgical and Chemical Engineering*, December, 1912) and the diagram giving these results is substituted as Fig. 241. The coefficient of $\frac{T_1 - T_2}{T_1}$ based on these results becomes 3.7 instead of 4.15, corresponding to a smaller indicated power than shown in the earlier results. The difference is not great for the conditions of blast refrigeration and makes power estimates based on the subsequent curves in this quotation somewhat high and correspondingly safe. Tests on both wet and dry compression were given in the original paper but now the dry is so much superior that the wet compression tests have been dropped and allusions to them omitted.

to know in addition the quantity of heat to be removed to determine the actual horse-power required.

The quantity of blast used being commonly measured in thousands of cubic feet per minute, the quantity of heat required to be removed per 1000 cu. ft. of blast is obviously the most convenient basis, but we are at once confronted with the difficulty that, as we change the temperature of the air, we change the volume of a given weight as well, 1000 cu. ft. at 70° F., becoming 900 cu. ft. at 21° F.; so that in considering the quantity of water-vapor contained in the blast as affected by refrigeration we not only diminish it by the fact that a cubic foot of space will contain less moisture at 21° F. than at 70° F.,

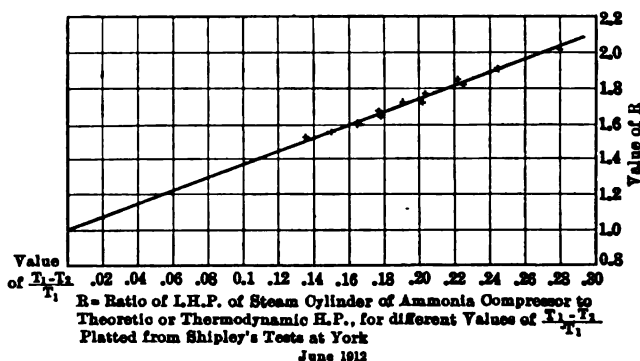


Fig 241. Chart showing ration of actual to theoretical horse-power required for refrigeration with different temperature ranges.

for instance, but that there are only nine-tenths as many cubic feet for a given weight of blast.

To overcome this difficulty the standard temperature at which blast is measured is taken at 70° F., at which 1000 cubic feet of air weigh exactly 75 lbs., and all calculations are based on 75 lbs. of air, correction being made for variation in volume. For the convenience of those desiring to make calculations on blast drying, a diagram (Fig. 242) is given herewith, which gives various relations of this standard quantity of air, based on its temperature.

The lower half of the diagram contains three curves whose abscissae are temperatures, and their ordinates quantities of heat above 0° F.

The straight line I shows the sensible heat, above that at 0° F., of 75 lbs. of air at any given temperature.

The upper curve gives the quantity of heat present above 0° F., in the water-vapor which will saturate 75 lbs. of air at different temperatures.

The latter quantity is not that given in steam tables as the "total heat of steam," but represents as nearly as may be the heat which

would require to be removed by refrigeration in order to reduce the vapor present in the air to the quantity sufficient for its saturation at 0° F.

This is made up as follows, for temperatures up to the freezing point:

1. The sensible heat of the ice above 0° F. (the specific heat taken as 0.50).

2. The latent heat of freezing.

3. The heat of vaporization.

These are all to be taken for the given temperature and the quantity of moisture actually present in 75 lbs. of air at that temperature.

Above the freezing point the conditions are altered; for part of the water, as soon as condensed, will not wait to be cooled down to the temperature of the refrigerating coils, but will drip off them soon after its deposition. As a fair estimate, therefore, one-half of the sensible heat (above 32° F.) for all the vapor in excess of that present at freezing is added to the other items.

This is shown on the diagram as curve II.

The lower curve III is derived by adding the ordinates of the first two and represents, therefore, all the heat requiring to be removed to reduce the air from saturation at a higher temperature to saturation at 0°.

The small quantities of heat ΔQ , of which these larger quantities are made up, are each removed at a different temperature, and therefore correspond to a different T_1 , in formula (I); hence these total quantities cannot be applied directly in that formula, but the latter must be put into the form

$$HP = R \frac{778}{33,000} \Delta \left(\frac{T_1 - T_2}{T_2} \right)$$

and integrated in order to give numerical results. This would be so tedious a process as to be useless if done analytically, but may be done conveniently by the application of the entropy diagram invented by Professor J. Willard Gibbs of Yale University many years since, and brought to the attention of the engineering world at large some fifteen years ago by Mr. Macfarlane Gray of England.

To many it will be a matter of indifference how the results are reached, provided only that they are reached correctly and swiftly. To these it may be said that entropy is a mathematical quantity depending upon heat and temperature, such that, when any thermal operation is plotted with temperature for abscissae and entropy for ordinates, the mechanical work involved is represented by the area included, precisely as it is with coördinates of pressure and volume in the ordinary indicator-diagram. This quantity has been determined for 75 lbs. of dry air, for the vapor contained in it, and for the sum of

these, exactly as for the corresponding quantities of heat, and these are plotted on the upper side of the same temperature axis as the latter. These curves are numbered respectively IV, V and VI.

The theoretical or perfect cycle of operations of the ammonia-compression machine is represented on this diagram by a rectangle whose right-hand end is the ordinate at the condensing temperature of the ammonia. Its top is a horizontal line at a height determined by the total entropy of the air to be refrigerated, and its bottom is one at a height determined by the entropy after refrigeration. (These will be called hereafter the lines of maximum and minimum entropy respectively.) Its left-hand end is determined by the suction or absorption temperature of the ammonia, which must be low enough to absorb heat from the air at the lowest temperature to which the latter is to be reduced. In practice the suction temperature is never less than 10° F. lower than this; and similarly the compression or condenser temperature is never less than 10° higher than that of the condensing water.

Under normal conditions cooling-water at 70° F. to 75° F. will always be available for condensing purposes in hot weather, and the maximum condenser temperature used in these diagrams is accordingly 85° F.; also, in all the cases taken for analysis in this article, this is the condenser temperature assumed, unless otherwise stated.

If we assume a uniform difference of temperature of 10° on the two sides of the expansion coils, we might construct a curve lying uniformly 10° F. to the left of the total entropy curve, that is, having a temperature 10° F. lower for the same ordinate in each case, and the lower left-hand corner of every rectangle would lie on this line, thus determining the rectangle completely, as the top and bottom lines are in all cases the lines of maximum and minimum entropy, and the right-hand end is the condenser temperature as before, the left-hand end being then determined by the intersection of the line of minimum entropy with the proposed curve. This curve, however, is not drawn on Fig. 242 for the reason that the area of the rectangle so determined would have to be multiplied by R , which would have to be determined from the absorption and condenser temperature in each case, in order to give the actual power required.

In order to avoid this necessity three auxiliary curves are plotted in dotted lines, which give the actual power requirements direct, with an assumed temperature difference in all cases of 10° F. at the refrigerating coils, and for three different condenser temperatures, respectively 85° F., 70° F., and 55° F., corresponding to the temperature of cooling-water available under different conditions and at different seasons.

The simple rule for the use of these curves is: Draw the lines of

maximum and minimum entropy, both extending to the proper condenser temperature on the right, and the latter extending to the left to its intersection with the corresponding dotted curve; at this point erect the vertical which completes the rectangle. The area of this rectangle in square inches gives the horse-power required per 75 lbs. of air for refrigeration between the limits chosen.

At various heights on the diagram the difference in temperature between the entropy curve and the assumed condenser temperature is taken, increased by 10° F., and the sum multiplied by R as determined from $\frac{T_1 - T_2}{T_1}$ for that point. This product is not in any way to be considered as a temperature, but only as a length, and is set off to the left of the condenser temperature used, with the ordinate for which the temperature difference was taken.

These points are connected by the dotted curves, and when the left end of the rectangle is drawn upward from the intersection of lines of minimum entropy with the appropriate curve, its right end and top being, as before, the condenser temperature chosen and the line of maximum entropy, it is evident that the length (and therefore the area) of the rectangle has been increased in the ratio R , thus giving actual horse-power.

In using these curves care must be taken to use the one corresponding to the condenser pressure in the given case. If this be different from any of those given, the curve corresponding can be interpolated by eye with all the accuracy necessary for most purposes.

It must also be noted that the curves are only correct for the "direct expansion" system, that is to say, where the ammonia is expanded in the coils over which the air passes.

In the brine-circulation system the ammonia is expanded in coils immersed in a tank of brine, which is afterwards circulated through coils in the refrigeration chamber. It is obvious that this system requires twice the expense for coils or pipe surface, and also requires twice the temperature-interval between the temperature of the expanding ammonia and that of the air, required by the direct-expansion system, since the heat requires to be transmitted through the walls of two sets of pipes instead of one. It is for the latter reason that the curves given are not correct for the brine system. To make them correct for this case at least 20° F. should be added, instead of 10° F., to the difference of temperature between the points on the entropy curve and the condenser temperature. This of course would give a new value of $\frac{T_1 - T_2}{T_1}$ and a new and larger value of R to correspond, so that the length of the rectangle for this case would be very materially augmented.

This, of course, means that the power required would be augmented in the same degree, and the cost of equipment in the same degree also, or even more, owing to the high cost of the second set of cooling coils in addition to the increased compressor capacity required.

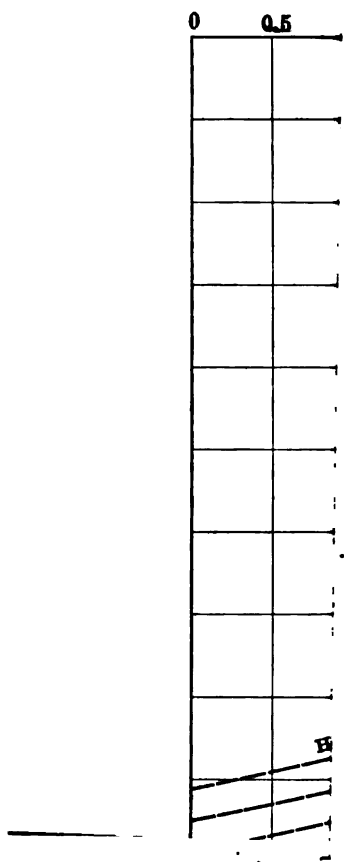
The danger to persons in the cooling chamber, from the escape of ammonia in direct expansion, is a minimum, since no one is ever required to enter it during operation and but seldom at any time; the danger of explosive mixtures of ammonia with air does not exist and, in case of a bad break in the coils, the charge would be no more irrevocably lost in the blast in the cooling chamber than in the brine tank. Only one possible danger exists, which is, that brass parts in the path of the blast would be rapidly destroyed if persistent leaks of ammonia occurred; but as the use of brass or bronze in such a situation is unusual and may readily be avoided altogether this is not a serious matter.

Under all circumstances there does not seem to be a sufficient reason for the use of the brine circulation now that the process of blast-drying is an established success and the need for the precautions required in an experimental plant no longer exists.

It is my conviction that, for the reason given above, the eventual progress of blast-drying will be along the lines of direct-expansion, and the curves of Fig. 242 have, therefore, been calculated on this basis. Should anyone desire them for brine circulation they can readily be calculated from the entropy table given and the formula for the value of R using a temperature difference for heat-transmission of 20° F. or 25° F., as might be found most consonant with the results of other experience with brine-circulation systems.

It might be as well to point out that the "total entropy" curve does not give the entropy for anything but saturated air; if the air be not saturated (as it generally is not), it is necessary to know both the dew-point and the temperature in order to determine the entropy. In that case the entropy of the water-vapor alone at its dew-point must be taken from the "entropy of vapor" curve and added to the entropy of the air at its temperature, as taken from the "entropy of dry air" curve. This is most conveniently done with dividers. The total entropy so determined will be above the total entropy curve at the dew-point temperature, and below it at the air temperature.

In regard to the temperature to which the air should be refrigerated some consideration is necessary. From Fig. 239 it is evident that the reduction in the weight of vapor for each degree the temperature is lowered is very slow after 25° F. is passed, and even at 32° F. is not rapid. At the same time the horse-power curves show that the power requirements increase rapidly for very slight reductions of temperature, and it is evident that the ratio of expenditure to gain is increasing so enormously that the balance point is soon passed.



line of maximum entropy, above the line of minimum entropy, and to

so enormously that the balance point is soon passed.

This is shown by Fig. 243, in which is plotted the ratio of water removed from 75 lbs. air below 40° F. to the power required for its removal. This is based on 70° F. condenser-temperature and single-stage non-regenerative refrigeration.

The saving in fuel in the furnace is directly proportional to the water removed, and the cost of plant and its operation nearly proportional to the power required, so it will readily be seen from Fig. 243 that a limit must soon be reached from the commercial point of view.

In summer all the uniformity possible would be reached by refrigerating to 32° F., and all trouble from ice formation would be avoided by not going below this point.

As the weather became colder and the dew-point fell so as to be sometimes below this point, the diminished refrigeration required, and the lower temperature of cooling water available, would enable the same plant to maintain a lower temperature and still retain the uniformity desired by reducing the temperature of the air below the lowest natural dew-point probable.

This change being entirely under control of the manager would lead to no sudden changes, and would give a coke consumption in summer so nearly the same as that in winter that the difference would probably be inappreciable, since as between a refrigeration temperature of 32° F. and one of 22° F., with a blast temperature of 1000° F. and normal coke practice, the saving for the latter would be about 2 per cent.

Using this chart as an implement of investigation we may now proceed to examine various methods of refrigeration.

In order to represent these methods graphically, and at the same time avoid marring the diagram Fig. 242, for independent use, it is reproduced in Fig. 244 with the rectangles representing the cases to be discussed drawn upon it.

In order to facilitate comparison and reference certain data corresponding to frequent summer conditions, may be assumed, namely: a temperature of 85° F., and a dew-point of 70° F., a condenser-temperature of 85° F., and that the air is to be refrigerated down to 25° F.

Let us also draw for convenience on Fig. 242 the line of 10° F. temperature-difference parallel to the curve of total entropy (VII).

The conditions assumed are then represented on the diagram by the area $aJHda$.

The rectangle drawn for these conditions is $ZJHG$, and its area is $5.60 \times 1.89 = 11.56$ sq. in., corresponding to 11.56 h.p. for drying 75 lbs. of air between the limits and under the conditions assumed.

It is evident that the area below the curve of total entropy and the line of maximum entropy, above the line of minimum entropy, and to

the left of the line of condenser-temperature, represents the theoretical minimum work for the performance of that amount of refrigeration. This must be increased in practice by moving the curve of total entropy 10° F. to the left to give the necessary temperature-head. This

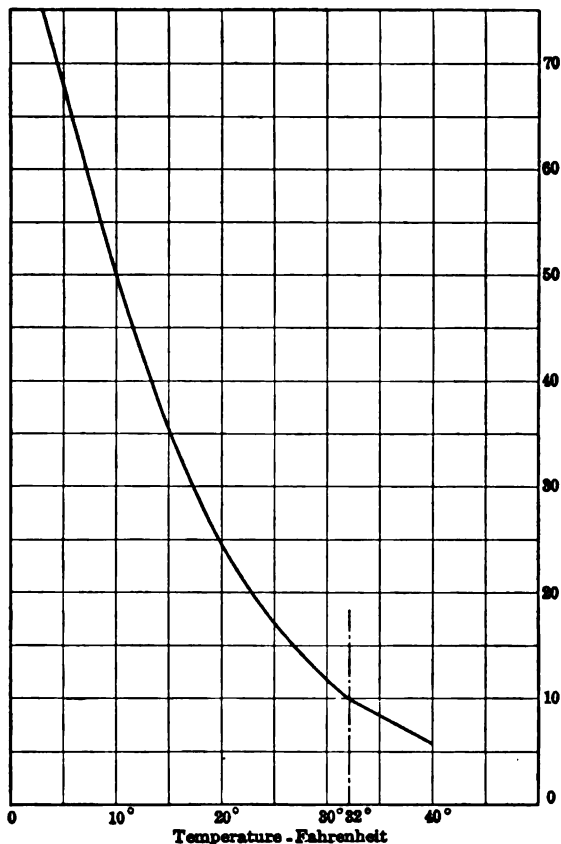
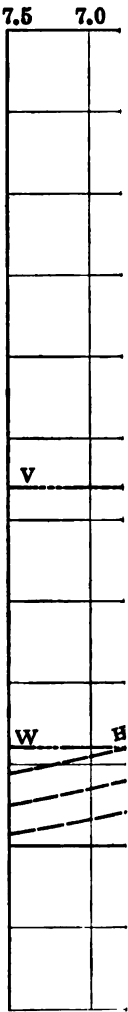
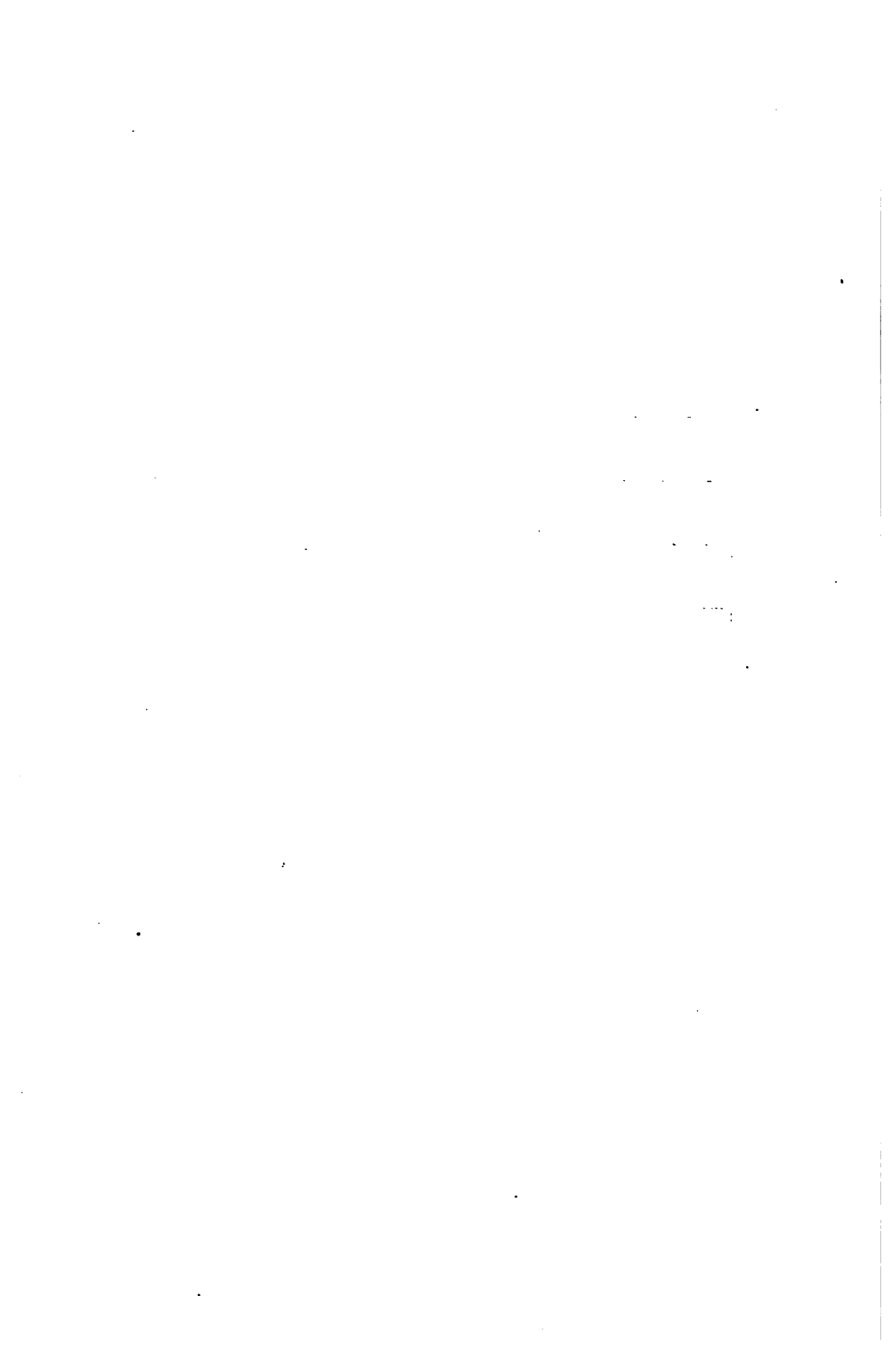


Fig. 243. Horse-power required per pound of water removed per minute in refrigerating blast to temperatures below 40° Fahr. (Direct expansion, single-stage, non-regenerative refrigerator, condenser temperature 70° Fahr.).

is the curve of 10° F. temperature-difference on Fig. 244, and is approximately a diagonal line across the diagram, making the area roughly triangular. On the other hand, the energy-diagram of the ammonia refrigerating cycle is, as already stated, a rectangle, and as it must be as large in every direction as the diagram of energy required, it is obvious that there must be a large quantity of waste room in the former diagram and that, accordingly, energy is being wasted.

This is also evident from an inspection of Fig. 239 since this shows





that of all the moisture contained in the air at 70° F. half is precipitated when the temperature is lowered to 50° F., and of that removable down to 25° F. almost two-thirds, yet the heat of all this is removed at the temperature of 25° F.

This is precisely as if, in pumping from a shaft 45 feet deep, in which three-fifths of the water entered in the upper 20 feet, we put one pump at the bottom and let all the water run down to that level before pumping it out. It is really much worse than this, because in pumping heat the power required increases much faster than the head, while with water this is not true.

The remedy is as obvious in refrigeration as it is in pumping, to have two pumps, catch the greater part of the heat near the top of its scale and pump it out from there, pumping from the lower level only the heat which comes in at or near that level, a much smaller quantity.

This means the use of two ammonia-compressor cylinders, one working from the 15° F. suction-temperature as before, the other working from a much higher suction-temperature, say 36° F., both, of course, working to the same condenser-temperature.

The rectangle for the latter of these extends from the line of maximum entropy for the case assumed, *JK* in Fig. 244, down to the line *NM* through 46° F., on the "total entropy curve," the end lines being drawn as before, the whole rectangle being *JKLM*.

The rectangle for the first-mentioned cylinder extends from the line *MLN* down to that of minimum entropy *GH*, the completed rectangle being *MNGH*.

The area of the first of these is $3.50 \times 1.25 = 4.375$ square inches; of the latter $5.60 \times 0.64 = 3.575$ square inches; total 7.95 square inches, corresponding to 7.95 horse-power per 75 lbs. of air, as compared with 11.56 horse-power for doing the same work in one stage.

This involves also the great advantage that most of the water is removed at a temperature above freezing, so that the quantity of ice which can form is greatly reduced, even in the coils of the second stage.

Three stages could similarly be used, but with a much smaller saving, as an inspection of the area outside the "85 degree horse-power curve" will show, so that the added complication of another stage would probably be a poor investment, especially as other considerations, to be mentioned presently, contribute to reduce the relative economy and desirability of this step.

The air leaving the refrigerator chamber is at the temperature of 25° F., and it is plain on the briefest consideration that this may be used for cooling the incoming air, with a saving of power to the refrigerating machine.

What the amount of this cooling will be is, of course, not a question of entropy, but simply one of heat. It is not, however, one of

easy algebraic solution, since the total heat of the vapor is a very complicated function of the temperature, that of the air being, for narrow ranges, a simple one of direct proportion.

It is for this purpose that the curves of heat are added below those of entropy on the diagram.

The problem is: Given 75 lbs. of dry¹ air at 25° F., allowing a temperature-difference of 10° F., and using the counter-current system of cooling, to what temperature will 75 lbs. of air at 85°, saturated with vapor at 70° F., be cooled?

Neglecting the insignificant superheat of the vapor, the air must be cooled from 85° F. to 70° F. before the moisture will be a factor, and the specific heat of air being constant this will obviously warm the dry air up from 25° F. to 40° F.

As 10° F. difference of temperature to give the necessary thermal head is assumed, the dry air will be discharged at 75° F., and the heat absorbed by it, from 40° F. to 75° F., is obviously that available for cooling the saturated air below 70° F.

Taking from the curve "heat of dry air" that due to 35° F. difference of temperature, we measure it off (towards the axis) from the 70° F. point on the curve of total heat; it comes to 1992 British thermal units, the line through which intersects the total heat curve at 58° F.

This transaction is shown by the lines A¹B¹C¹ on Fig. 244. From this it is obvious that the line of maximum entropy for this case is that through the temperature 58° F., which is simply transferred vertically over to the total entropy curve. This line is shown at VP in Fig. 244, the whole rectangle being VPHG, whose area is $1.11 \times 56 = 6.22$ square inches = 6.22 horse-power, as compared with 11.56 horse-power for the same work without regeneration.

With this improvement can now be combined that of stage refrigeration, by which is obtained the two rectangles PQRS and TSHG, whose areas are $3.72 \times 0.66 = 2.45$ square inches, and $5.6 \times 0.45 = 2.52$ square inches, corresponding to a total of 4.97 horse-power per 75 lbs. air when refrigerated in stages and with the aid of regeneration.

From this it will be seen that great economies are effected by the use of the direct-expansion system, by refrigerating in two stages and by regenerating the "cold" in the air which has passed through the system, for the purpose of cooling down the incoming air.

There is also another possibility in the direction of economy which received consideration in the original development of this process by Mr. Gayley and was brought out in the discussion of my paper, that is, the utilization of the reduction of the volume of the air due to its

¹ The trivial amount of water-vapor still present is neglected, being only 0.4 per cent. of the total weight.

being compressed for delivery to the furnace. If the blast pressure is fifteen pounds obviously the volume of the blast at atmospheric temperature is reduced to fifty per cent. of its original amount, and obviously also since the quantity of vapor present per cu. ft. is a function of temperature only, this means that if the air were saturated before compression half the moisture would be squeezed out of it by compression, if its temperature were reduced to that of the atmosphere after leaving the blowing engine. This means plainly two things. First, less moisture to be condensed; second, the moisture present will be condensed to any desired limit with a higher dew-point. This also means a saving in power.

In the early plants where the air was cooled by the introduction of vast masses of pipe coils into its path it was virtually impossible to have chambers which would withstand the blast pressure necessary, and of a size to contain this mass of coils, without, prohibitive expense and perhaps danger, therefore in these the refrigeration is always done before the air enters the blowing engine, but in later years the system of cooling the air by direct contact with a "rain" cooled by the refrigerating coils has been introduced and this eliminates the necessity for coils in the refrigerating chambers, thus reducing the latter to relatively small dimensions, and this makes possible the use of the "post-compression" system of refrigeration.

This system has been worked out and applied by the Carrier Air Conditioning Company of America, which also uses regeneration and refrigeration in stages. A plant designed by them is shown by Figs. 245, 246 and 247. Fig. 245 shows a side elevation of the ammonia compressor (motor-driven), and the ammonia condenser, also of the brine coolers, while behind, rising above the shed roof of the compressor house, are shown the outlines of the cooling chambers. Fig. 246 shows a plan of the same equipment. *C*, *D*, *E* and *F* are the various cooling chambers which can best be described by reference to Fig. 247, but before passing to this it is well to note that the cooling chambers are so arranged in reference to the blast main *A* that the blast can be thrown through them by closing the intermediate valve *B*, or by closing the cut-off valves in the connecting necks and opening the intermediate valves, the cooling chambers can be cut off and the blast can go to the stoves direct, thus giving an opportunity to throw the refrigerating plant out of service without shutting down the furnace.

Fig. 247 shows the coolers *C*, *D*, *E*, *F* as if they were arranged in a straight line so as to show the currents through them. *C* is a heat exchanger in which the cold outgoing air is warmed up almost to inlet temperature by the warm incoming air from the blowing engine. This accomplishes two good results. It sends the air warm to the stoves, and, much more important, it does a part of the cooling which would

have otherwise to be done by more expensive means, i.e., direct refrigeration.

From *C* the blast passes into *D*, which is simply a spray tower supplied with natural cold water. This continues the refrigeration begun in *C*, and remembering that cooling-water is generally available at or below the dew-point of the air, and that the density of the air is

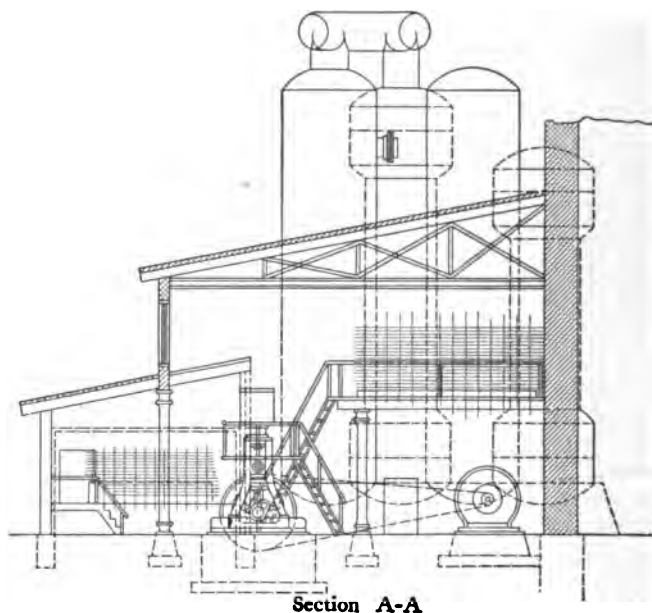


Fig. 245. Elevation of carrier dry-blast plant
(ammonia compressors motor driven).

approximately doubled by compression before entering this system, it is obvious that the temperature produced by such natural cooling-water will precipitate much of the moisture. From *D* the air passes into the base of *E*, which like *C* is a heat exchanger. The cold air coming from the second spray tower presently to be described, and at the lowest temperature reached in the system, enters at the top of *E* as shown, while the incoming air to be refrigerated enters at the bottom, and passing in counter-current through the tubes of the exchanger is cooled to an important extent, while the outgoing blast is, so to speak, prewarmed for its entrance into *C*, because of course it is by-passed around *D* and passes directly from *E* to *C*. From *E* the incoming air enters the second spray tower *F* cooled with water refrigerated to a temperature between 32° and 40° F. These spray towers have two great advantages. First, they avoid the use of expensive tubes for heat transmission. Second, they obtain immediate and practically unlimited contact with the air to be cooled, so that the drop in temper-

ature between the two is practically negligible. The incoming air therefore is reduced virtually to the temperature of the cold rain, or somewhere about 38° F. From Fig. 242 it will be seen that at this temperature the moisture is .38 lb. per cubic foot; from this, remembering the compression of the air under which these conditions

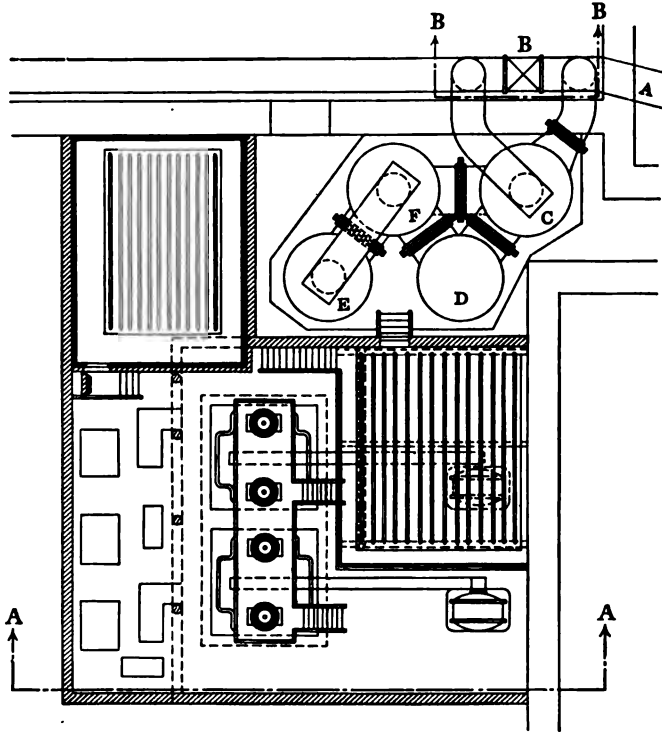


Fig. 246. Plan of Carrier dry blast plant.

prevail, we find .19 lb. per cubic foot as the equivalent moisture in uncompressed air. This corresponds to a dew-point of 22° and is as low as it is economical to go in blast refrigeration.

One point of much importance is to be noted here. The temperature of the cold rain is well above the freezing point, while to secure a corresponding degree of refrigeration on the precompression system it is necessary to refrigerate well below the dew-point, and this introduces all the complications caused by ice.

Both the pre-compression and post-compression systems have their advantages and their disadvantages. One of the principal merits claimed for the dry blast in its early days was that it produced a uniformity in conditions, in the quantity of air and the oxygen contained therein, delivered to the furnace per minute, and a considerable

number of metallurgists attributed entirely to this fact the improvement in the operation of the furnace which it brought about. To the latter view I have never been able to subscribe. I shall later show what seemed to me conclusive reasons for believing that the great advantage of the dry blast lies in its dryness. At the same time the advantages of uniformity are not for a moment to be ignored. Now it is obvious that if the blast be reduced to a constant temperature, say to 25° F., which was the practice at one time,

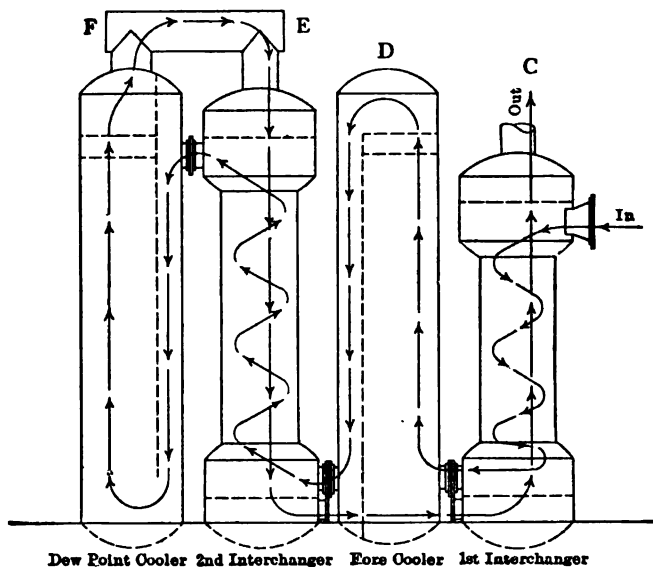


Fig. 247. Diagram showing arrangement of cooling towers and regenerators of carrier plant in proper relation.

nearly all the moisture is removed from it, as shown by Fig. 242, and the quantity remaining is made perfectly uniform while the temperature and therefore the density of the air are likewise rendered uniform. It then becomes necessary only to run the blowing engine at a constant speed to secure all the advantages of a constant weight of air per minute to the furnace. If a constant quantity of air be blown it is obvious that its volume after compression must vary from hour to hour and day to day on account of the varying pressure required by the blast-furnace which produces a corresponding variation in the density of the air. Therefore if the quantity of moisture per cubic foot be kept the same by having an absolutely uniform temperature after refrigeration, the variation in the number of cubic feet due to the cause just explained still causes some variation in the actual quantity of moisture delivered to the furnace.

In recent years it has become the practice to change the speed of

the blowing engine according to changes in the temperature of the inlet air, to compensate for the corresponding variations in its absolute volume. No difficulty is found in keeping constant the weight of air delivered to the furnace by this simple means. The Carrier Air Conditioning Company has applied the same idea to securing a constant quantity of moisture in the blast irrespective of the blast pressure, regulating the dew-point by means of changes in the temperatures of the refrigerating apparatus; it has also developed a mechanism whereby this change is automatically made, thus securing a constant weight of moisture with varying blast pressure.

So far no one has as yet introduced a compensation for variations in barometric pressure, though doubtless that refinement will come at some plants in time.

Another respect in which the pre-compression and the post-compression system differ is that with the former all the air is delivered to the blowing engine cold, and the reduction in volume resulting from this causes a proportional reduction of the power required by the main blowing engine. On the other hand, the refrigeration imparted to the air at a considerable expense, is lost except for this saving. Now it can easily be proven by thermo-dynamics that if both the refrigerating machine and the blowing engine were perfect the total power required to refrigerate the air down to any desired temperature, and then compress it from that low temperature, would be exactly the same as the power required to compress it directly from atmospheric temperature. It becomes therefore a question as to which machine is the most efficient, a question easy to decide, for we know that good blowing engines are from 85 to 90 per cent. efficient, while even good refrigerating plants are only around 55 per cent. It is obvious, therefore, that it pays to save power in the refrigerating machine even at the expense of the blowing engine. But another point is to be considered here. When the pre-compression system is used the blast containing much of the heat of compression passes at once to the stoves and of course reduces the amount of heat to be imparted by the stoves proportionately, whereas the post-compression system, if applied the same as the original pre-compression systems, would deliver strongly refrigerated air to the stoves with corresponding increase in the heat required of them.

It is partly to overcome this disadvantage that the Carrier Company uses the first exchanger shown in its system, since by the aid of this it can warm up the outgoing air to within a few degrees of the temperature of the incoming air. This puts matters on practically an even basis as regards the heat to be supplied by the stoves.

Using the post-compression system permits giving paramount consideration to the power requirements, and these, as has been pointed

out, are greatly reduced by the use of exchangers and the two-stage system. They are also further reduced by the fact that the temperature to which the air must be refrigerated is not nearly so low as under the pre-compression system to reduce the moisture to the same number of pounds per minute. This has a very decided bearing on the power requirements, since it has been shown (see article in *Metallurgical and Chemical Engineering*, December, 1912, above mentioned) that the power required for any given quantity of refrigeration (Q) is

$$HP = 0.0235 Q (Z + 3.7 Z^2)$$

in which Z is equal to $\frac{T_1 - T_2}{T_1}$ and this is obviously less as the temperature to which we refrigerate is raised. Moreover, while the quantity of refrigeration for the condensation of the moisture is the same, that for the cooling of the air is less, because the temperature to which the given weight of air is cooled is not so low in the post-compression system as in the other, it is therefore obvious that the power required must be very materially less with this system than with pre-compression.

A considerable advantage in the use of exchangers inheres in the post-compression system for the reason that the greater density of the air greatly increases the ease with which heat may be imparted to or abstracted from it, and the exchangers can therefore be smaller on this system than they could for an equal degree of efficiency if used on the pre-compression system.

The slightly lowered temperature at which the air is delivered to the stoves constitutes the principal objection to this system when the blast-furnace pressure is twelve pounds or more, but when the pressure is less than this the reduction in volume of the air is very much smaller and the advantage of the system falls off proportionately, so that there may be cases in which it is desirable to use the pre-compression system, but in such cases there is no excuse for not using two-stage cooling and regeneration.

It may be thought that the cost of the regenerator is just that much addition to the total cost, but this is by no means the case. The regenerator does, without consuming any energy, a part of the refrigeration which would otherwise have to be done by the refrigerating machine, and therefore makes a proportionate reduction in the size of refrigerating equipment required, whose cost per unit of work done is of course very much greater than the cost of the regenerator.

By the use of the rain system two great advantages are obtained. First: The avoidance of the heavy cost for brine-circulating coils and the chambers in which to enclose them. Second: The avoidance of the additional drop of temperature required to force the heat from

the air into the brine through pipe walls which involves a lower temperature of refrigeration for a given degree of moisture removal. The whole plant is made smaller and more compact and in every way cheaper and better by this system.

If rain be used for carrying the heat from the refrigerating coils to the air, as is most desirable, and if the second stage of the refrigeration takes the temperature below the freezing point as a pre-compression system should probably do, it becomes necessary to use a non-freezing solution for this purpose. Brine, preferably made with calcium chloride, should be used and as this obviously takes up most, if not all of the moisture from the air which it cools, an evaporator must be arranged at some point in the circuit to remove the accumulated water from the system and maintain the strength of the brine. In such a case a heat exchanger should be installed between the refrigerating system and the evaporator so that the "cold" in the incoming and the heat in the outgoing brine may both be conserved.

INDEX

- Air, compressed, 370
 - moisture in, 384
 - preheated, 190
 - valves, automatic, 131
 - in blowing engines, 124
- Allis-Chalmers Co., 148, 179, 181, 187
- American Institute of Mining Engineers, 52, 54, 58, 160, 164, 229, 298
- American Iron and Steel Institute, 257
- American Kron Scale Company, 47
- American Society of Mechanical Engineers, 179, 384
- American Steel & Wire Co., 263
- Ammonia-compression refrigeration machine, 387, 389
- Arrangement of plant, 359, 373
 - boilers and engines, 380
 - casting house, 373
 - disposal of iron and slag, 382
 - distance apart of furnaces, 376
 - elevation of furnace, 379
 - railroad tracks, 373
 - stoves and hot-blast main, 378
- Ashland furnace construction, 268
- Babcock & Wilcox, 117
- Babcock & Wilcox boiler, 107, 112, 113
- Bachman, F. E., 264, 293
- Bacon, C. J., 187
- Baker bin, 38
 - rotating top, 67, 72, 87, 90
- Barrows, W. A., 52
- Barrows, filling, 11
- Bassett, H. A., 257
- Bauman bell and hopper, 54
- Bed, definition, 328
- Bell and hopper, 48, 53, 54, 62
 - handling for repairs, 93
 - hoisting apparatus, 91
 - operating apparatus, 87
- Beesmer process, 337
- Bethlehem Steel Co., 187, 239, 291
- Bian gas washer, 308
- Bibus pump, 168
- Bins, storage, 31
 - Baker suspension type, 38
 - Brown parabolic, 32
 - Hoover and Mason, 34
 - Wellman-Seaver-Morgan, 35
- Birdsboro Foundry & Machine Co., 249
- Blast-furnace, abrasion by the stock, 235
 - air, preheated, 190
 - arrangement of plant, 373
 - auxiliaries, 359
 - blowing apparatus, 119
 - boiler plant, 99
 - capacity, 2, 8
 - charging apparatus, 38
 - chemical action on lining, 233
 - classification by fuel, 6
 - compressed air supply, 370
 - constructions adopted, 236
 - definition of blast furnace, 2, 4
 - delivery of stock, 16
 - development from Catalan forge, 3
 - dry blast, 383
 - electric supply, 371
 - filling, 48
 - fuel requirements, 3, 4
 - gas current, abrasive action, 235
 - handling system, 285
 - seal, 59
 - gases, 99
 - general arrangement, 359
 - hand-filling, 11
 - handling iron and cinder, 328
 - materials, 7
 - hearth and bottom, 238
 - heat of blast and slag, 4
 - heating the blast, 100
 - hoisting engines, 9
 - in mechanical charging, 38
 - hot-blast stoves, 190
 - labor, 6, 8, 11, 14, 15, 17, 61, 98, 173, 331, 339
 - lining, chemical action on, 234
 - mechanical filling, 15, 60
 - output, 7

- Blast-furnace, plant, required size, 6
 - power plants, 103
 - pressure, 236, 241
 - pumping machinery, 363
 - requirements, 4
 - scales, 44
 - size of plant, 6
 - stack, construction of, 233
 - stand pipes, 366
 - stock distribution, 49
 - hoisting, 9
 - line recorder, 93
 - storage bins, 31
 - stoves needed per furnace, 225
 - temperatures of hearth, 233 —
 - thin-lined, 262
 - tops, 62, 64, 65, 67, 82
 - union with steel plants, 102
 - unloading machinery, 17
 - waste-water system, 369
 - water-supply system, 359
 - weighing materials, 44
- Blow-off valves, 220
- Blow pipes, 278
- Blower, turbo, 155
- Blowing apparatus, 119
 - air valves, 124
 - choice of type of engine, 185
 - compounding, methods of, 135
 - disconnected compound, 140, 141
 - engine friction, 136, 137, 144
 - engines, review of types, 142
 - gas-driven engine, 172
 - inertia of reciprocating parts, 136, 137, 144
 - long cross-head type, 119, 145
 - pot valves, 126
 - steam valves, 151
 - vertical quarter crank engine, 142
- Boil, definition, 329
- Boiler house, location, 380
- Boiler plant, 99
 - Babcock & Wilcox type, 107, 112, 113, 117
 - cleaning, 116
 - cylinder boilers, 101
 - Dutch oven, 109, 113, 115
 - gas burners, 113
 - grates, precautions, 115
 - Heine boiler, 105
 - horizontal tubular, 103
 - Rust boiler, 112
 - Stirling boiler, 110
- Boiler plant, water-tube, 103, 104
- Bosh, construction of, 246
- Boynton, A. J., 217, 284
- Brassert-Witting whirler, 301
- Breaking iron in beds, 330
- Brick stoves, 200
- Brickwork of furnace, 271
- Bridges, traveling, 18
- Brine-circulation system, 387, 393
- Broden, Albert, 261
- Brown, Alexander E., 17, 32, 39, 67
- Brown, Fayette, 67
- Brown Hoisting Machinery Co., 17 333, 353
- Brown-hoist fast plant, 17, 22
 - rotating top, 67, 68
 - skip hoist, 41, 42
 - storage bin, 32
- Browning & Co., Victor R., 354
- Bucket, clam-shell, 353
 - filling apparatus, 15, 38, 43
 - hoist, counterweighting, 42
 - system of distribution, 80
- Burden, 44
- Burners, stove, 216
- Bustle pipe, 278
- Calibration of air-measuring apparatus, 164
- Car, cinder, 348
 - dumpers, 29
- Carbonaceous fuel to reduce iron, 2
- Carbonates containing iron, 1
- Cards, steam and air, 125, 149, 151, 153, 154, 166
- Carnegie Steel Co., 15
- Carrier Air Conditioning Co. of America, 399, 403
- Carrier, W. H., 384
- Cast iron defined, 3
- Casting in chills, 329
 - in sand beds, 328
 - machines, 339
- Catalan forge, 2, 3
- Charcoal furnaces, 7
- Charging, mechanical, 60
 - scales, 45
- Chemical action in furnaces, 233
- Checkers in hot blast stoves, 224
- Child, E. T., 149
- Chills, casting in, 329
- Chimney valves, 217
- Cinder, casting, 356

- Cinder, concrete, 356
 - handling, 328
 - skimming, 344, 347
- Cleaning boilers, 116
- Cleaning the gas, 285
 - Bian gas washer, 308
 - Brassert-Witting whirler, 301
 - Cottrell electrical method, 325
 - disintegrator systems, 310
 - downcomers, 285, 287, 291
 - dry cleaning, 301, 317
 - Duquesne spray tower, 306
 - dust catchers, 291
 - content, 301, 320
 - Dyblie whirler, 301, 303
 - efficiency of dry cleaning, 305
 - explosion doors, 288
 - Feld gas washer, 314
 - Fowler and Medley vertical gas washer, 313
 - Halberger-Beth system, 305, 317, 322
 - Kapnograph, 318
 - Mullen gas washer, 295
 - outlets from furnace top, 287
 - Reco centrifugal gas washer, 315
 - Schiele system, 308, 310
 - Schwarz-Bayer disintegrator gas washer, 310
 - scrubbing process, 297
 - sepulchre gas washer, 316
 - Theisen gas washer, 308
 - wet cleaning, 306, 308
 - Zachocke system, 306, 308
- Cleveland Furnace Co., 356
- Coke, abrasive quality, 235
 - barrows, 13
 - breakage, 65
 - shatter test, 66
- Cold-blast valves, 214
- Coleman, E. P., 179
- Colorado Fuel and Iron Co., 41, 112
- Compounding, methods of, 135
- Compressed air for cleaning boilers, 117
 - supply, 370
- Concrete, cinder used for, 356
- Condensation of moisture, 385
- Condensers for blowing engines, 167
- Construction of stack, 233
- Constructions adopted for blast furnaces, 236
- Cook, E. B., 261
- Cooling plates, 246, 255, 359
- Cores, definition, 330
- Corliass air valves, 124
 - steam valve, 151
- Cottrell gas cleaning method, 325
- Counter-current principle, 2
- Counterweighting in filling, 42
- Crane, Brown hoist, 353
 - use in cast house, 332
- Cross-head blowing engines, 119, 145
- Croxtan, D. T., 356
- Dalton's law, 383
- Detroit Iron & Steel Co., 263
- Denton, Prof., 389
- Dew point, 384
- Diagram factor of air cards, 166
- Diehl, A. N., 229, 298, 322
- Disintegrator systems of cleaning gas, 310
- Distribution of stock, 49
 - bucket system, 80
- Ditch around hearth jacket, 243
- Double-bell furnace top, 62
- Downcomer, 285, 287, 291
- Dry blast, 383
 - advantages, 401
 - brine-circulation system, 387, 393
 - condensation of moisture, 385
 - moisture in air, 384
 - post-compression system of refrigeration, 399, 403
 - rain system of refrigeration, 399
 - refrigeration of moisture, 385, 389
- Dry cleaning of gas, 301, 317
- Duquesne furnaces, 80, 332
 - revolution, 15, 49, 61, 66, 67, 102, 288, 289, 328, 333
 - spray tower, 306
- Durham bell and hopper, 54
 - iron-pipe stoves, 199
- Dust catchers, 291
 - content in gas, 301, 320
- Dutch oven in boiler plants, 109, 113, 115
- Dyblie whirler, 301, 303
- Electric hoisting engine, 10
 - supply, 371
- Electrical method of cleaning gas, 325
- Electricity for ore-handling machinery, 30
- Elevation of furnace, 379
- Empire Iron & Steel Co., 155
- Engine house, location, 380
- Engineers' Society of Western Pennsylvania, 229
- Engines, blowing, 119

- Engines, blowing, choice of types, 185
 compound, 135
 condenser, 167
 cut-off, 152
 diagram factor of air card, 166
 disconnected compound, 140, 141
 efficiency, 166
 energy, transmission of, 136
 friction, 136, 137, 144
 gas-driven, 172
 horizontal cross-compound, 147
 horizontal-vertical, 143
 inertia of reciprocating parts, 136,
 137, 144
 inside-crank, 148, 149
 long cross-head type, 119, 145
 market value of power produced, 187
 pressure, steam and air, 138
 reciprocating and turbine combined,
 170
 steam and air cards, 125, 149, 151,
 153, 154, 166
 steam valves, 151
 steeple type, 145
 stresses, 152
 tail-slide, 149
 turbo blower, 155
 vertical quarter-crank, 142
 vertical tandem cross-compound, 145
- Entropy defined, 391
- Equalizer for blast temperature, 227
- Equipment of plant, 359
- Explosion doors, 288
- Fairbanks charging scale, 45
- Federal Furnace Co., 374
- Feld gas washer, 314
- Filling-barrows, 11
- Filling the blast furnace, 48
 bell and hopper, 53
 breakage of the coke, 65
 bucket system of distribution, 80
 gas seal, 60
 skip, 61
 spiral, 52
 stock line recorder, 93
- Firebrick, 271
 drying the lining, 277
 laying, 274
 stoves, 200
- Firmstone, Frank, 58, 173
- Firmstone, H., 193
- Firmstone bell and hopper, 54
- Forbes, W. A., 298, 300, 322
- Ford-Parkes furnace top, 82
 system of bucket filling, 39
- Fowler and Medley vertical gas washer,
 313
- Frey, H. J., 187
- Friction, engine, 136, 137, 144
- Fritz, John, 135
- Fuels for blast furnace, 3, 4
 classification of furnaces by, 6
 mineral coal, 347
 phosphorus content, 5
 physical strength, 5
 porosity, 5
 sulphur content, 5
- Fume of furnace gas, 286
- Furnace main connections, 368
 tops, accessibility for repairs, 91
 Baker tops, 67, 72, 87, 90
 bell-operating apparatus, 87, 91
 double-bell, 62
 Ford-Parkes top, 82
 gas outlet, 287
 guiding the bell movement, 85
 McKee rotating top, 67, 76, 79
 Neeland type, 65
 protection of, 258
 repairs on bell, 93
 Roberts type, 64
 rotating, 67, 76, 79
 Rowe type, 64
 shape, 261
- Gas, analysis, 285
 cleaning and washing, 285
 current, velocity, 235, 286
 dust content, 301
 determinator, 320
 engine *vs.* steam turbine, 372
 fume, 286
 moisture determinator, 320
 seal, 59
 volume determinator, 320
 water vapor in, 297
- Gas-driven blowing engines, 172
 adapting to variable loads, 175
 adoption in Europe and America, 173
 cleaning the gas, 175
 difficulties, 174, 176
 double acting with tandem cylinders,
 176
 expense of operating and maintenance, 177

- Gas-driven blowing engines, four-cycle
 - type, 179, 181
 - indicator cards, 183
 - Koerting type, 178, 179
 - speeds, 183
 - two-stroke cycle type, 178
 - types, 178
 - uncertainties of operation, 176
- Gases, Dalton's law, 383
 - from furnaces, 15, 99
 - in furnaces, burners for boilers, 113
- Gayley, James, 385, 387, 398
- General Electric Co., 155, 160, 187
- General Electric turbo blower, 159
- Gibbs, J. Willard, 391
- Glendon Iron Co., 58, 173
- Glendon iron-pipe stoves, 199
- Granulation, 352
- Grates in boilers, 115
- Gray, Macfarlane, 391
- Halberger-Beth gas-cleaning system, 305, 317, 322
- Hand-filling, 11, 49
- Handling iron and cinder, 328
 - breaking the iron, 330
 - casting in chills, 329
 - in sand beds, 328
 - machines, 339
 - cinder ladles, 348
 - hot-metal ladles, 338
 - iron trough and skimmer, 344
 - Killeen skimmer, 344
 - laying out slag dump, 351
 - liquid pig iron, 337
 - mixer, 337
 - molding up sand beds, 336
 - molds, 343
 - pig breaker, 332
 - Pollock hot-metal car, 338
 - recovering iron from slag, 358
 - runners, iron, 346
 - skimming the cinder, 344, 347
 - slag, disposal of, 346
 - granulation, 352
 - Treadwell hot-metal car, 339
 - Uehling machines, 340
- Handling raw materials, 7
- Hartman, John M., 227, 350
- Hearth of a furnace, 238
- Heated blast, 4
- Heine Safety Boiler Co., 105
- Helander, A. H., 168
- Helander condenser, 168
- Heyl & Paterson Co., 340, 342
- High-furnace, 2
- Hoisting in mechanical charging, 38
 - power, 9
- Hoover and Mason apparatus, 18, 22, 25, 34
- Horizontal tubular boilers, 103
- Hot-blast stoves, 190
 - baffle walls, 198
 - blow-off valves, 220
 - bottom and base ring, 223
 - brick stoves, 191, 200
 - central combustion chamber stove, 201, 207
 - checkers, 224
 - chimney valves, 217
 - cleaning gas, 229
 - cold-blast valves, 214
 - domes, 223
 - Durham iron-pipe stoves, 199, 226
 - equalizing the blast temperature, 227
 - firebrick stoves, 200
 - Glendon iron-pipe stoves, 199
 - heating surface, 228
 - hot-blast valves, 209
 - iron-pipe stoves, 192
 - joints of iron-pipe stoves, 193
 - Kennedy-Morrison valve, 218
 - location in plant, 378
 - McClure stoves, 201, 204, 205
 - McKee-Neilson stoves, 206
 - main location, 378
 - number per furnace, 225
 - packing, 221
 - pipes, shape of iron, 198
 - regenerator, 191
 - Roberts three-pass stove, 203
 - Roberts two-pass, 207
 - roof of iron-pipe stove, 198
 - size, 228
 - Spearman burner, 216, 218, 219
 - stack for stoves, 222
 - stove burners, 216
 - castings, 220
 - three-pass stove, 201
 - two-pass stoves, 205
 - valves and fittings, 209
- Hot-blast valves, 209
- Hot metal, 338
- Hulett, George, 22
- Hulett unloader, 22

- Illinois Steel Works, 103, 187, 263
 Indiana Steel Co., 374
 Inertia of reciprocating parts of engines, 136, 137, 144
 Ingersoll Rand Co., 131
 Ingersoll Rogler valve, 131
 Inland Steel Co., 219, 240, 242
 Inwall of furnace stack, 254
 Iron, carbonates containing, 1
 cast, 3
 handling, 328
 metallurgy of, 2
 ores of, 1
 oxides of, 1
 prevalence in earth, 1
 recovering from slag, 358
 requirements to produce a ton, 6
 sulphides of, 1
 wrought, 3
 Iron-pipe hot blast stoves, 192
 Iroquois Iron Co., 155
 Isabella furnaces, 385, 387
 Iverson valve, 133

 Jones, T. C., 352
 Jones, W. R., 337

 Kapnograph, 318
 Kennedy, Hugh, 200
 Kennedy, John S., 227
 Kennedy, Julian, 77, 90, 128, 209, 262, 289, 374
 Kennedy inlet valve, 128, 129
 -Morrison valve, 218
 rotating top, 77
 Kerr, D. G., 62
 Killeen, Michael, 344
 Killeen skimmer, 344
 Kluttz, W. L., 46
 Koerting injector, 316, 317
 gas engines, 178, 179

 Labor in furnaces, 6, 8, 11, 14, 15, 17, 61, 98, 173, 331, 339
 Lackawanna Steel Co., 178
 Ladd, James B., 335
 Ladles for hot metal, 338
 Langen charger, 57
 Larry cars, 43
 Lidgerwood Manufacturing Co., 11
 Lining of furnaces, 262
 chemical action on, 234
 drying, 277
 Longdale Iron Co., 56, 193, 198, 260

 Lorraine blast furnace, 284, 374
 Low furnace, 2
 Lucy furnaces, 80, 262, 263,

 McClure & Sons Co., George W., 201, 209
 McClure stove, 201, 204, 205, 220
 McKee, Arthur G., 38, 76, 79, 206
 McKee-Neilson stoves, 206
 McKee rotating top, 67, 76, 79
 McMurray, Max, 263
 Mains, water, 367
 Mechanical charging, 60
 filling, 15
 Mesta cross-compound steam blowing engine, 150
 cross-head blowing engines, 121
 Machine Co., 133, 154, 168, 177, 181
 Metallurgy of iron, definition, 2
 Midvale Steel Co., 62, 128
 Mineral fuel, 347
 Mixer, 337
 Moisture in air, quantity, 384
 Molding up sand beds, 336
 Motor-driven hoist, 10
 Mullen, B. F., 295
 Mullen gas washer, 295
 Musconetcong furnace, 227

 National Steel Co., 65
 Neeland, M. A., 15, 65, 80
 furnace top, 80
 hoisting apparatus, 39
 Neilson, James B., 4, 190
 Neilson two-pass stoves, 206
 Nordberg, B. V., 126, 149
 compressors, 144
 Manufacturing Co., 126, 140
 Northern Iron Co., 155, 264, 293

 Ore barrows, 13
 bridges, 18
 -handling machinery, 17, 30
 unloading from vessels, 17
 Ores of iron, 1
 Otis Elevator Co., 11, 89
 Output of blast furnaces, 7
 Oxides of iron, 1

 Parabolic bin, 32
 Pennsylvania Steel Co., 300
 Penstocks, 278
 Phosphorus in fuel, 5
 Pig breaker, 332

- Pig iron, definition, 328
- Pioneer Blast Furnaces, 379
- Pipes, water main, 367
- Plan of blast furnace plant, 373
- Plant, auxiliaries and general arrangement, 359
 - size of, 6
- Pollock cinder ladle, 349, 350
- Pollock Co., W. B., 216, 238, 338, 350
- Poppet valves, 126, 127, 151
- Porosity of fuel, 5
- Port Henry Furnace, 264
- Post-compression system of refrigeration, 399, 403
- Pot valves, 126
- Power boiler cleaners, 117
 - hoists for stock, 9
 - house, location, 380
 - plants, 103
- Pressure in blast furnaces, 236
 - in hearth, 241
- Pueblo, skip hoist used at, 41
- Pumping machinery, 363
 - centrifugal pump, 364
 - direct-acting steam, 363
 - electric motors, 365
 - triplex plunger, 365
 - vertical plunger, 364
- Rain system of refrigeration, 399
- Rateau, M., 155
- Rateau turbo blower, 156
- Raw materials, 7
- Reading Iron Co., 261
- Reco centrifugal gas washer, 315
- Reciprocating engine combined with turbo blower, 170
- Refrigeration of moisture in air, 385-405
 - post-compression system, 399, 403
 - rain system, 399
- Regenerator, 191
- Republic Iron and Steel Co., 46, 379
- Revolving furnace tops, 67
- Reynolds, Edwin, 127
 - poppet valve, 127
- Rice, Richard H., 160, 161, 187
- Richards, J. W., 165
- Riedler, Mr., 126
- Roberts & Co., Frank C., 204, 207, 209, 214, 217, 264, 387
 - Frank C., 64, 261, 263
 - furnace top, 64
- Roberts three-pass stoves, 203
- Roberts two-pass stove, 207
- Roessing-Ernest Co., 315
- Rogler valve patents, 131
- Rotating furnace tops, 67
- Rotoff, Mr., 80
- Rowe furnace top, 64
- Runners, iron, 346
- Rust, E. G., 41, 112
- Rust boiler, 112
- Sand beds, casting in, 328
 - molding up, 336
- Scale cars, 31, 43, 47
- Scales, 44
- Schiele system, 308, 310
- Schroter, Prof., 389
- Schwarz-Bayer disintegrator gas washer, 310
- Scott, James, 262
- Scrubbing gas, 297
- Sepulchre gas washer, 316
- Sewer system, 369
- Shaft of blast furnace, 254
- Shatter test of coke, 66
- Shipley, Thomas, 389
- Siemens, William, 191
- Size of blast furnace, 6
- Skimmer, iron, 344
- Skip filling, 43, 61
 - skip hoist, 39
 - counterweighting, 42
 - dumping the skip, 42
 - location of sheaves, 41
- Slag, disposal of, 346
 - granulation, 352
 - laying out the dump, 351
 - necessary heat, 4
- Slick, E. E., 62, 128
- Southwark air valve, 130
 - cross-head blowing engine, 120
 - Foundry & Machine Co., 130, 140, 145, 149, 153-155, 167
 - turbo blower, 156
- Sow, definition, 328
- Spearman burner, 216, 218, 219
- Spiral filling, 52
- Stack construction, 233
 - abrasion by stock, resistance to, 235
 - Ashland construction, 268
 - blow pipes, 278
 - bosh, 246
 - bustle pipe, 278

- Stack construction, chemical action, resistance to, 233
 conditions to be met, 233
 constructions adopted, 236
 cooling plates, 246, 255
 ditch around hearth jacket, 243
 drying the lining, 277
 filling the packing space, 276
 firebrick, 271
 gas current, resistance to, 235
 hearth and bottom, 238
 Inland Steel Co.'s construction, 241
 laying firebrick, 274
 lining, thin, 262
 penstocks, 278
 pressure, resistance to, 236
 shaft or inwall, 254
 shape of furnace top, 261
 stock line, protection of, 258
 temperature, resistance to, 233
 top of furnace, 258
 tuyère zone, 245
 water cooling, 242
 wicket, 282
 Stacks for hot-blast stoves, 222
 Stand pipes, 366
 Steam hoisting engines, 9
 turbine *vs.* gas engine, 372
 Steece, R. C., 294
 Steel castings for stoves, 221
 plants connected with furnaces, 102
 Stenbakken, Ole, 219
 burner, 217, 219
 Stewart, Samuel, 350
 Stirling boilers, 110, 118
 Stock, delivery to furnace, 16
 distribution, laws of, 49
 hoisting, 9
 house, 7
 line, protection of, 258
 recorder in furnace, 93
 Storage bins, 31
 Stove burners, 216
 castings, 221
 Streeter-Amet Co., 46
 Stresses in blowing engines, 152
 Sulphide of iron, 1
 Sulphur in fuel, 5

 Temperatures in furnace hearths, 233
 Tennessee Coal & Iron Co., 263
 Theisen, Herr, 175
 gas washers, 308, 310
 Thomas, Samuel, 379
 Thompson Steel Works, Edgar, 60, 62, 128, 337, 344
 Thwaites, B. H., 173
 Tod Co., William, 138, 147, 153, 154, 168, 175, 179, 183
 Traveling bridges, 18
 Treadwell cinder ladle, 349, 350
 Treadwell Engineering Co., 339, 350, 351
 Trough, iron, 344
 Turbo blowers, 155
 air governing device, 159, 160
 calibration of air meters, 164
 combined with reciprocating engine, 170
 disadvantages, 165
 driven by low-pressure turbine, 170
 failures, 166
 General Electric type, 159
 inefficiency, 165
 pulsation of discharge, 165
 Southwark Rateau type, 156
 Venturi meter, 159
 Tuyère zone, 245

 Uehling, E. A., 340
 United States Steel Corporation, 62, 217, 387
 Unloading ore from vessels, 17

 Valentine, S. G., 164, 165
 Valves, air, 124
 automatic air, 131
 blow-off, 220
 chimney, 217
 cold blast, 214
 Corliss, 151
 hot-blast, 209
 Ingersoll Rogler valves, 131
 Iverson valve, 133
 Kennedy inlet valve, 128, 129
 poppet, 126, 151
 pot, 126
 Reynolds' poppet valve, 127
 Southwark air valve, 130
 steam, 151
 Varnes, S. K., 300
 Velocity of gas current, 286
 Venturi meter, 159
 Vertical two-cylinder hoisting engine, 9

 Wages of ore handlers, 15
 Warwick Iron Co., 263

- Washing the gas, 285
Waste-water system, 369
Water-supply system, 359
 furnace main connections, 368
 mains, 367
 pumping machinery, 363
 stand pipes, 366
 waste water, 369
Water tube boilers, 103, 104, 116
 vapor in gas, 297
Watt's steam engine, 87
Weighing raw materials, 44
Weimer, P. L., 144, 173
Weiss condenser, 167
Wellman-Seaver-Morgan apparatus, 18,
 22, 35
West, Arthur, 187
Westinghouse Machine Co., 155
Wet cleaning of gas, 308
Whitwell, William, 191
Wicket, 282
Witherbee, T. F., 54
Witherbee bell and hopper, 57
Woodward Iron Co., 350
Wrought iron defined, 3
York Manufacturing Co., 389
Zschocke system of cleaning gas, 306, 308
 towers, 308, 311

13-

[illegible]

LD 21-20m-5,'89 (9269a)

aver x
4.00 m

YC 19019



